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Development of the social brain during adolescence

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ABSTRACT

This article describes recent research which informs our understanding of changes in social cognition during adolescence. The focus will be on mentalising, the ability to attribute and manipulate mental states in the self and others. Mentalising is supported by the medial prefrontal cortex (MPFC) and both anterior and posterior regions of the temporal lobes. In the past decade, studies have demonstrated development during adolescence of white and grey matter brain structure, with most protracted changes observed in frontal and temporal lobes, including those regions supporting mentalising. This article presents evidence that certain aspects of social cognition continue to change during adolescence, highlighting results from recent research investigating the use of theory of mind information in a communicative context. The findings highlight how adolescence, and not only childhood, is a time of continued maturation of brain and behaviour, when education and the environment can have an impact on cognitive development.

Desarrollo del cerebro social durante la adolescencia

Palabras clave:
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RESUMEN

Este artículo describe resultados de investigaciones recientes sobre cambios en la cognición social durante la adolescencia. Se centra en la mentalización, la capacidad de atribuir y manipular estados mentales en uno mismo y en los demás. La mentalización está asociada con la corteza prefrontal media (MPFC) y las regiones anterior y posterior de los lóbulos temporales. En el último decenio hay estudios que demuestran que a lo largo de la adolescencia se desarrolla la estructura cerebral tanto de la sustancia blanca como de la gris, observándose los cambios más notables en los lóbulos frontal y temporal, que incluyen regiones en las que se asienta la mentalización. Este artículo demuestraque determinados aspectos de la cognición social siguen desarrollándose durante la adolescencia, presentando los resultados de estudios recientes que investigan la utilización de la teoría de la mente en un contexto comunicativo. Los resultados subrayan cómo la adolescencia, y no sólo la niñez, es una etapa de maduración continua del cerebro y del comportamiento, cuando la educación y el entorno pueden influir en el desarrollo cognitivo.

Adolescence can be defined as the period of life that starts with the beginning of puberty and ends when a stable, independent role in society is attained (Steinberg, 2010). The transition from childhood to adulthood is a period of changes, both in terms of the environment and in terms of brain and cognitive development. In a proportion of individuals, adolescence is the time for the first onset of mental disorder, with an analysis by Kessler et al. (2005) revealing that 75% of adult mental disorder, including anxiety and mood disorders, schizophrenia, impulse-control and substance-use disorders, have their onset before 24 years of age. In addition, the leading causes of death in adolescence are accidents, violence, and suicide (Patton et al., 2009). These findings highlight the importance of increasing our understanding of both typical and atypical behavioural and brain development during adolescence.

Advances in the field of magnetic resonance imaging (MRI) in the last two decades have permitted for the first time to study the healthy living human brain during development. Research has

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been divided between structural MRI, which investigates anatomical changes in the brain (Giedd & Rapoport, 2010) and functional MRI, which investigates changes in neuronal activity via changes in blood flow. More recently, researchers have attempted to link these two measures and further explore the link between structural and functional changes during development, and how structural and functional brain maturation may account for behavioural changes observed in a wide range of situations and paradigms.

Two particular aspects of cognition are thought to show prolonged changes during adolescence. One aspect is cognitive control, which encompasses a range of cognitive processes ("executive functions"), including inhibition, working memory, planning, and attention (see Anderson, 2002; Luna, Padmanabhan, & O'Hearn, 2010 for reviews). The second aspect is social cognition, and will be the focus of this article. Social cognition encompasses all those cognitive processes that allow individuals to interact with one another (Adolphs, 1999; Frith & Frith, 2007). These range from the perception of facial expression, body posture, and eye gaze, to mentalising, the ability to attribute and manipulate mental states in the self and others (Frith & Frith, 2007). A wide network of brain regions have now consistently shown to be recruited during social cognition tasks (Frith & Frith, 2007; Van Overwalle, 2009). These regions form the "social brain", which is the brain basis for the capacity to process social signals (Frith & Frith, 2007).

Over the past 15 years, a large number of independent studies have shown remarkable consistency in identifying the brain regions that are involved in theory of mind or mentalising. These studies have employed a wide range of stimuli including stories, sentences, words, cartoons, and animations, each designed to elicit the attribution of mental states (see Amodio & Frith, 2006, for review). In each case, the mentalising task resulted in the activation of a network of regions including the posterior superior temporal sulcus (pSTS) at the temporo-parietal junction (TPJ), the anterior temporal cortex (ATC), or temporal poles, and the dorsal medial prefrontal cortex (MPFC) (Frith & Frith, 2007; Gallagher & Frith, 2003; Saxe, 2006). The agreement between neuroimaging studies in this area is remarkable and the consistent localisation of activity within a network of regions including the pSTS/TPJ and MPFC, as well as the temporal poles, suggests that these regions are key to the process of mentalising. However the specificity of these regions for processing social information is still investigated. For example the ATC supports semantic knowledge, including, but not limited to, social concepts and social scripts, and the dorsal MPFC may be more broadly recruited in meta-cognitive processes of reflecting on thoughts and intentions, that may not be social in nature (Frith & Frith, 2007).

In this article, I will first summarise the findings on structural brain development during adolescence, focusing in particular on those changes that take place in the mentalising regions of the social brain. I will then present the findings of early development of the understanding of false-beliefs and later developmental changes in theory of mind use, and describe the findings from functional neuroimaging studies investigating changes in social brain activation during adolescence. Finally, I will briefly highlight potential implications of these findings for education policy and practice.

Structural Development of the Social Brain

Post-mortem brain studies in the 1970s and 1980s had shown that synaptic density, which corresponds to the number of connections ("synapses") between neurons observed per unit of neuronal surface, increases drastically in the first few months and years of life and then progressively decreases during childhood in the visual and auditory cortex, and during adolescence in the prefrontal cortex (Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997; see Petanjek et al., 2011 for more recent data). Despite this evidence for early dendritic arborisation and later prolonged pruning of synaptic connections, it was until recently widely held that the brain was anatomically mature during adolescence, and that changes in social behaviour during this period of life were a result of hormones, social experience, and the changing social environment. These factors are likely to play a major role, but neuroanatomical development may also play a role. In the last couple of decades, results from large MRI studies investigating the development of the brain have provided further evidence that the structure of the brain continues to change during adolescence. Notably, the frontal and temporal lobes, which support social cognition, undergo the most protracted development in humans (Giedd et al., 1999; Gogtay et al., 2004; Shaw et al., 2008; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). Report that the peak cortical thickness, which is an index of the developmental timecourse of grey matter changes, is first reached in the occipital lobes, at age 7-9 years old, then in the parietal lobes (age 8-11), in the frontal lobes (age 8-13), and last reached in the temporal lobes (age 11-15).

A recent study provides further evidence of the prolonged development of those brain regions supporting mentalising (Mills, Lalonde, Clasen, Giedd, & Blakemore, 2014). This study analysed 857 structural scans from 288 participants aged 7-30 years old and focused on those four regions of the social brain described above: ATC, MPFC, TPJ, and pSTS. Developmental changes in three structural measures were investigated: grey matter volume, cortical thickness, and surface area. The findings indicated that grey matter volume and cortical thickness in MPFC, TPJ, and pSTS decreased from childhood into the early twenties, while the ATC increased in grey matter volume until adolescence and in cortical thickness until early adulthood. Surface area in all four regions followed a cubic trajectory, with a peak in late childhood or early adolescence before a decrease into the early twenties. Changes in grey matter structure are thought to correspond partly to synaptic reorganisation and to enable the fine-tuning of grey matter tissue according to experience and the environment.

A second aspect of brain structure that has been investigated using MRI is white matter volume and white matter fibres. Early studies had shown that during development neuronal axons, which make up the white matter fibres connecting brain regions, become coated in myelin sheath, and that myelination occurs progressively throughout the brain, with latest myelination observed in the higher association areas (Bonin, 1950). Longitudinal MRI studies have shown that white matter volume increases during development until the third decade of life (Giedd et al., 1999; Lebel & Beaulieu, 2011). This increase is thought to reflect myelination but also other processes such as increasing axon diameter, and may be associated with an increasing speed of signalling between neurons, which would in turn increase processing speed during development. More recent studies have used novel MRI techniques such as diffusion tensor imaging (DTI) and have shown that, similar to grey matter, the developmental timecourse of white matter changes vary across brain regions (e.g., Lebel, Walker, Leemans, Phillips, & Beaulieu, 2008).

In their recent study, Mills et al. (2014) note that the ATC is an area of the cortex which is linked to both the MPFC and limbic structures via the uncinate fasciculus, one of the last white matter tracts to reach maturity (Lebel et al., 2008), and suggest that perhaps the late myelination of the ATC projections allow a long window for learning social scripts. This highlights the importance for future studies of attempting to combine and integrate both white matter and grey matter data when studying structural changes in the brain during development.

To summarise, MRI research in the last two decades has shown that there are prolonged changes in both grey and white matter structures that occur during adolescence, and that these