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Review article

The development of social cognition in adolescence: An integrated perspective

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ABSTRACT

Social cognitive processes are critical in navigating complex social interactions and are associated with a network of brain areas termed the 'social brain'. Here, we describe the development of social cognition, and the structural and functional changes in the social brain during adolescence, a period of life characterised by extensive changes in social behaviour and environments. Neuroimaging and behavioural studies have demonstrated that the social brain and social cognition undergo significant development in human adolescence. Development of social cognition and the social brain are discussed in the context of developments in other neural systems, such as those implicated in motivational-affective and cognitive control processes. Successful transition to adulthood requires the rapid refinement and integration of these processes and many adolescent-typical behaviours, such as peer influence and sensitivity to social exclusion, involve dynamic interactions between these systems. Considering these interactions, and how they vary between individuals and across development, could increase our understanding of adolescent brain and behavioural development.

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1. Introduction

Adolescence can be defined as the period of life between puberty and the achievement of self-sufficiency and independence (Blakemore and Mills, 2014). This transitional period of development has long been associated with physical, social, behavioural and cognitive changes. More recently, advances in brain imaging technology have enabled increased understanding of structural and functional changes in the human brain during this developmental period (Blakemore and Mills, 2014; Casey et al., 2008; Ernst and Fudge, 2009; Lenroot and Giedd, 2006), and how they relate to social cognitive development. This review integrates recent research on the development of social cognition in adolescence within the context of other aspects of adolescent neurocognitive development, such as motivational and affective processing, decision-making and cognitive control.

2. The social brain

Social cognition refers to the ability to make sense of the world through processing signals generated by other members of the same species (Frith, 2007) and encompasses a wide range of cognitive processes that enable individuals to understand and interact with one another (Adolphs, 1999; Frith and Frith, 2007). These include social perceptual processes such as face processing (Farroni et al., 2005), biological motion detection (Pelphrey and Carter, 2008), and joint attention (Carpenter et al., 1998), in addition to more complex social cognitive processes involving inference and reasoning, such as mentalising, the process of mental state attribution. Such social cognitive processes enable us to understand and predict the mental states, intentions and actions of others, and to modify our own accordingly (Frith and Frith, 2007). Social cognition thus plays a critical role in the successful negotiation of complex social interactions and decisions (Crone, 2013).

A wide network of brain areas, referred to as the 'social brain' network, is involved in social perception and cognition (Adolphs, 2009; Frith, 2007). Regions within the social brain network include the posterior superior temporal sulcus (pSTS), temporoparietal junction (TPJ), dorsomedial prefrontal cortex (dmPFC; medial aspects of BA10), anterior temporal cortex (ATC), and the inferior frontal gyrus (IFG; Frith and Frith, 2007; Van Overwalle, 2009; Fig. 1).

Electrophysiological and functional magnetic resonance imaging (fMRI) studies consistently report the involvement of the pSTS in the perception and interpretation of biological motion and eye gaze (Pelphrey et al., 2004; Puce and Perrett, 2003). It has been proposed that the pSTS is involved in interpreting complex social gestures. The TPJ is involved in inferring others' mental states, as opposed to information that is merely known about others (Saxe and Kanwisher, 2003; Saxe et al., 2009). The dmPFC is activated in multiple cognitive processes, including inferring others' mental states and reflecting on the personality traits of oneself and other people (Frith, 2007). Frith (2007) has proposed that the dmPFC is involved in handling communicative intentions, which requires a second order representation of mental states. The ATC is involved in interpreting social narratives (Olson et al., 2013, 2007), processing social scripts (Frith, 2007; Frith and Frith, 2003) and integrating social memories with emotion (Olson et al., 2007; Pfeifer and Peake, 2012). The IFG, which is associated with a range of cognitive processes, has been implicated in action observation (Rizzolatti et al., 2001; Shaw et al., 2012) and understanding social situations (Carter et al., 2012).

While the coactivation of these regions has been demonstrated in many neuroimaging experiments involving social cognition tasks, the integration of these anatomically distinct brain regions is likely highly complex, and thus the specific contributions of individual regions within the network is debated, as is their specificity for processing social information (see Adolphs, 2010, for discussion).

3. The social brain in adolescence

Many social changes occur during adolescence. These include the fact that, compared with children, adolescents form more complex and hierarchical peer relationships and are more sensitive to acceptance and rejection by their peers (Brown, 2004; Steinberg and Morris, 2001). Although the factors that underlie these social changes are likely to be multi-faceted, one possible contributing factor is the development of the social brain. Certain social cognitive processes, such as face processing (Farroni et al., 2005), biological motion detection (Pelphrey and Carter, 2008) and joint attention (Carpenter et al., 1998), are present from an early age (see Baillargeon et al., 2010). However, more complex aspects of social cognition and the structure and function of associated brain networks continue to develop across adolescence and into early adulthood.

3.1. Structural development of the social brain in adolescence

Areas within the social brain network are among the regions that undergo the most protracted development in humans (Barnea-Goraly et al., 2005; Giedd et al., 1999; Gogtay et al., 2004; Shaw et al., 2008; Sowell et al., 2004, 1999), showing changes throughout adolescence before relatively stabilizing in the early to mid-twenties. Mills et al. (2014b) examined the structural developmental trajectories (grey matter volume, cortical thickness and surface area) of brain areas associated with mentalising. In a sample of 288 individuals with at least two brain scans between the ages of 7 and 30 years, they found that grey matter volume and cortical thickness decreased in medial Brodmann area 10 (dmPFC), TPJ, and pSTS from childhood into the early twenties. In contrast, the ATC increased in grey matter volume until early adolescence (~12 years), decreasing thereafter, whereas cortical thickness increased until early adulthood (~19 years). Surface area in all four regions followed a cubic trajectory, reaching a peak in late childhood or early adolescence, before decreasing into the early twenties (Mills et al., 2014b; Fig. 2).

The underlying cellular changes associated with a reduction in grey matter volume are still debated (Paus et al., 2008; Poldrack, 2010). There is evidence from animal and post-mortem human brain tissue studies for synaptic reorganisation and pruning (Huttenlocher and Dabholkar, 1997; Petanjek et al., 2011) and increases in myelination and axonal diameter in the PFC during adolescence (Yakovlev and Lecours, 1967). Both of these neurodevelopmental processes would result in decreases in grey matter volume. With little overall change in whole brain volume after late childhood (Mills et al., 2016), increased myelination and axonal diameter would result in increased white matter and decreased grey matter volume (Paus et al., 2008; Whitaker et al., 2016).

3.2. Development of social cognition and social brain function in adolescence

Recent neuroimaging and behavioural studies have shown developments in a number of social cognitive abilities and functional changes in associated brain networks across adolescence.

3.2.1. Face processing

A vast array of social information can be extracted from the faces of those around us, including identity, emotional expression and direction of eye gaze. In adolescence, new aspects of face processing become increasingly important, as more complex social