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Review

The amygdala: An agent of change in adolescent neural networks

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ABSTRACT

This article is part of a Special Issue "Puberty and Adolescence".

A unique component of adolescent development is the need to master new developmental tasks in which peer interactions become primary (for the purposes of becoming autonomous from parents, forming intimate friendships, and romantic/sexual partnerships). Previously, it has been suggested that the ability to master these tasks requires an important re-organization in the relation between perceptual, motivational, affective, and cognitive systems in a very general and broad way that is fundamentally influenced by the infusion of sex hormones during pubertal development (Scherf et al., 2012). Herein, we extend this argument to suggest that the amygdala, which is vastly connected with cortical and subcortical regions and contains sex hormone receptors, may lie at the heart of this re-organization. We propose that during adolescent development there is a shift in the attribution of relevance to existing stimuli and contexts that is mediated by the amygdala (e.g., heightened relevance of peer faces, reduced relevance of physical distance from parents). As a result, amygdala inputs to existing stable neural networks are re-weighted (increased or decreased), which destabilizes the functional interactions among regions within these networks and allows for a critical restructuring of the network functional organization. This process of network re-organization enables processing of qualitatively new kinds of social information and the emergence of novel behaviors that support mastery of adolescent-specific developmental tasks.

Contents

Introduction

Adolescence is rapidly becoming known as a unique developmental period that has implications for important changes in cognitive, affective, and emotional behaviors as well as underlying neural circuitry

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(see Scherf et al., 2012). A central feature of adolescent development is the need to master developmental tasks that are specific to this period of development and that require the emergence of completely novel behaviors. For example, individuals transitioning through adolescence have a new interest in developing romantic and sexual partnerships with peers, in large part because of pubertal development. They also have increasing needs to form loyal friendships with peers and to become autonomous and independent from parents (Eccles et al., 1993; Steinberg and Morris, 2001). These tasks lead adolescents to enhance the primacy of peer interactions and evince a social *reorientation* toward peers (Brown, 2004; Nelson et al., 2005). This reorientation supports the emergence of social competence and high-quality friendships with peers, two developmental tasks that foreshadow the quality of adult relationships and social functioning more generally (Capaldi et al., 2001).

These aspects of adolescent development raise difficult questions about how *new behaviors emerge* from behavioral and neural systems that are becoming increasingly stable across many domains at this very same time (e.g., reasoning abilities, reaction time, immune function; see Dahl, 2004). Previously, it has been argued that the emergence of new behaviors relevant to the developmental tasks of adolescence is likely to 1) require a fundamental re-organization in the way perceptual, cognitive, affective, and motivational systems work together, 2) be reflected in changes in the functional interactions (i.e., functional connectivity) between the neural regions that support these component systems, and 3) be influenced by pubertal hormones (Scherf et al., 2012). For example, in the domain of face processing, specific developmental tasks of adolescence may induce the need to extract qualitatively new kinds of information from faces, such as the attractiveness, trustworthiness, competence, and social status of a face, particularly for peer-aged faces (see Fig. 1). This need may be instantiated neurally in the form of a concomitant functional *re-organization* (i.e., new patterns of functional interactions) among neural circuits that support and integrate perceptual, affective, and cognitive aspects of face processing. Scherf and colleagues also argued that gonadal hormones will likely increase motivational and affective inputs that modulate functional connectivity among existing visuoperceptual, cognitive, social and affective neural regions supporting face processing (see Fig. 1). In other words, they expect that the dynamical interactions (e.g., functional connections) between face processing regions are fundamentally altered as a result of the surge of gonadal hormones and the resulting new task demands for face processing in adolescence. This process fundamentally enables the

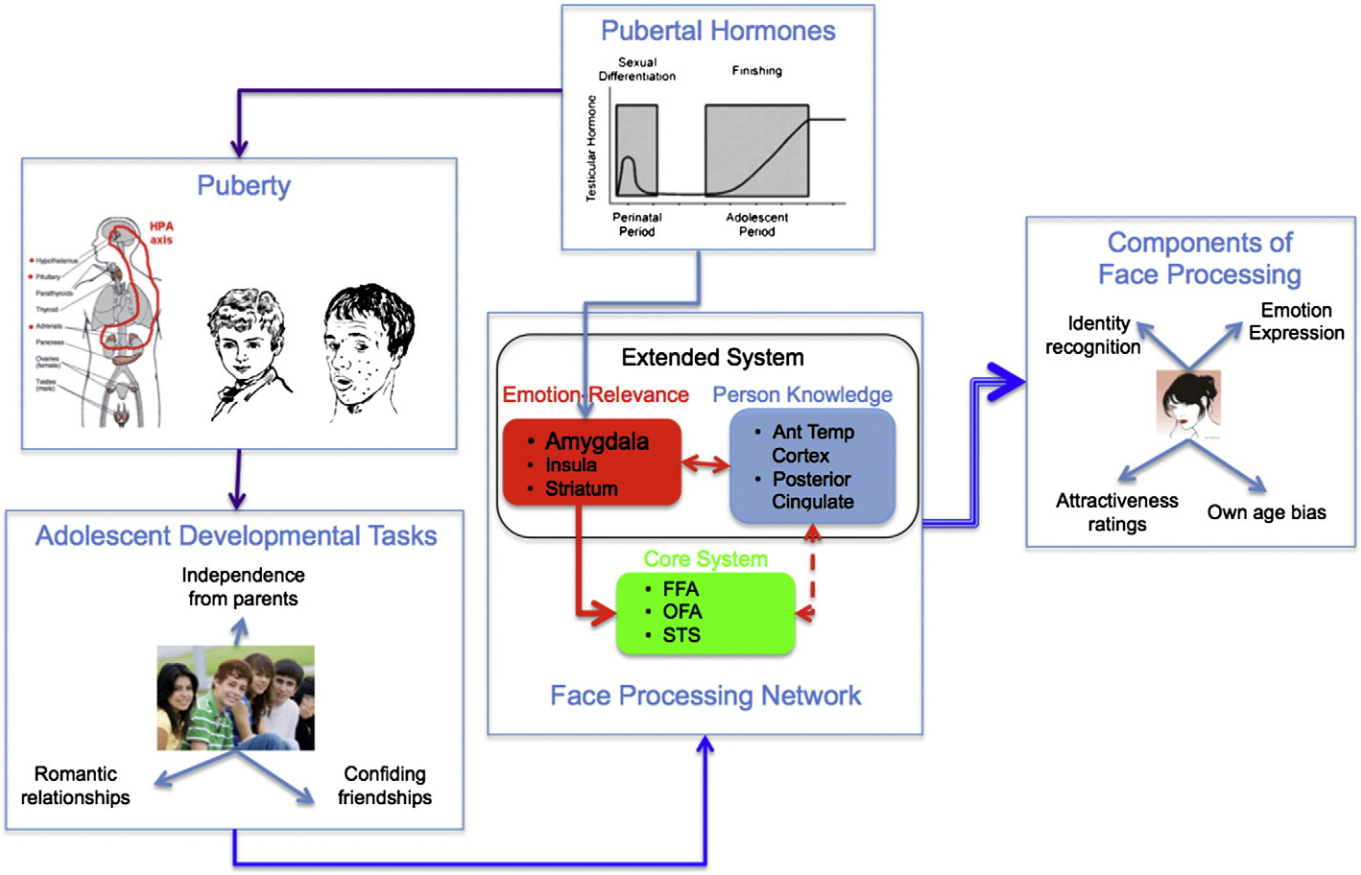

Fig. 1. A schematic representation of the Scherf et al. (2012) network-based model that emphasizes a restructuring of the dynamical interactions between existing neural regions to enable the emergence of new behaviors and particularly those relevant to the specific developmental tasks of adolescence. The model includes three hypotheses about the dynamic changes that are predicted to initiate the emergence of new social and affective components of face processing in adolescence (i.e., fine-tuned attractiveness ratings and an own-age bias in identity recognition). In Hypothesis 1 (dark purple lines), Scherf and colleagues predicted that the pubertal hormones that initiate the development of secondary sex characteristics and sexual dimorphisms in the structure of the face and brain are also likely to influence motivation to master new developmental tasks, such as developing confiding friendships and romantic relationships with peers. This is manifest in the brain as a modulation in the functioning of limbic circuitry (particularly the amygdala), which induces dynamic changes in the functional organization of many neural circuits that interact with the amygdala, including the face processing system. These developmental tasks will in turn, drive the *emergence of new social/affective components of face processing* (Hypothesis 2—blue lines). In other words, puberty induces adolescents to be socially and affectively motivated to encode new social information from faces that is related to these developmental tasks, such as the attractiveness, trustworthiness, competence, and social status of a face, particularly for peer-aged faces. Finally, in Hypothesis 3 (red lines), Scherf and colleagues argued that the dynamical interactions between neural face processing regions are fundamentally altered as a result of the surge of gonadal hormones and the resulting new task demands for face processing. Specifically, the *functional/effective connectivity*, or temporal synchrony, between regions of the face-processing network will change with the emergence of these new components of face processing in adolescence. This reorganization allows for new socially relevant information to be encoded from faces, leading to new components of face processing behavior. Reprinted with permission from Developmental Cognitive Neuroscience.