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A Neurocognitive Model of Self-Concept Development in Adolescence

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adolescence, self, fMRI, prefrontal cortex, perspective taking, social comparison

Abstract

When and how do changes in self-concept emerge in adolescence, and which factors facilitate positive self-concept development? This review summarizes recent research findings on self-concept development based on neurocognitive development studies. Self-concept goes through formative changes in adolescence, including linear and nonlinear changes in perspective taking, social comparison, and self-evaluation. In this review we (*a*) present a neuroscientific model of self-concept development by relating processes that drive self-concept changes to neuroscience discoveries and (*b*) elaborate on the roles of early life experiences and environmental support factors in fostering self-concept development in adolescence. This review concludes that self-concept changes pose vulnerabilities as well as opportunities for adolescent development.

Contents

1. INTRODUCTION

Adolescence is an important transition phase in life during which young people (ages 10–24) develop from children dependent on parents into young adults with mature social and societal goals (Dahl et al. 2018, Sawyer et al. 2018). One of the hallmarks of adolescence is forming a stable and positive self-concept, which can be defined as knowledge and beliefs about oneself. The processes underlying self-concept development change extensively throughout childhood and adolescence (Pfeifer & Peake 2012, Sebastian et al. 2008). Developing a generally stable and positive self-concept is beneficial for several developmental milestones in life, such as educational and work commitments, social and academic identity formation, and overall well-being (Harter 2012, Oyserman et al. 2012, Schwartz et al. 2012).

From a developmental perspective, it is important to develop a self-concept that is stable and well-structured but also malleable. Structure and stability help us to predict and understand the world in an efficient manner, while context-based malleability helps us to tune our thoughts, feelings, and behaviors to the opportunities and constraints of the situation (Oyserman et al. 2012, Robins et al. 2008). In this review, we discuss how adolescents' self-concept changes through cognitive advances and social experiences in relation to friends and family members (Becht et al. 2017) and also in the context of social and societal demands (Fuligni 2019). Recent studies on dynamic changes in the adolescent brain have provided novel perspectives on self-concept development in the formative phase of adolescence (Blakemore & Mills 2014).

1.1. Defining Self-Concept and Behavioral Development in Adolescence

Self-concept has been described as a socio-cognitive construct, shaped by both cognitive advancements and social interaction (Harter 2012). Self-concept can be subdivided into two main constructs: self-concept clarity and self-concept appraisal (Pfeifer & Peake 2012, Schwartz et al. 2012) (see **Figure 1**, **Table 1**). Self-concept clarity is the extent to which knowledge and beliefs about the self are clearly and confidently defined, internally consistent, and temporally stable (Campbell et al. 2003). Self-concept clarity encompasses both the stability of self-concept across time and the lack of conflict about one's character and traits. Self-concept clarity was previously found to increase linearly between the ages of 12 and 21 (Wu et al. 2010), but other studies have reported nonlinear changes between the ages of 13 to 18 and ages 17 to 23 (Crocetti et al. 2016a,b). Possibly, changes in self-concept clarity are more clearly described by within-subject change than by general age patterns (Branje et al. 2021).

Self-appraisal has been described as encompassing the nonobservable, estimated qualities of the self (Bailey 2003, Harter 2012). It comprises what we do and how we appear and is based on subjective descriptions of our traits (e.g., "I am attractive") rather than objective facts (e.g., "I have blue eyes"). Self-appraisal is usually studied by asking participants to evaluate whether or to what extent positive and negative traits fit the self (Rapee et al. 2019). These evaluations of one's

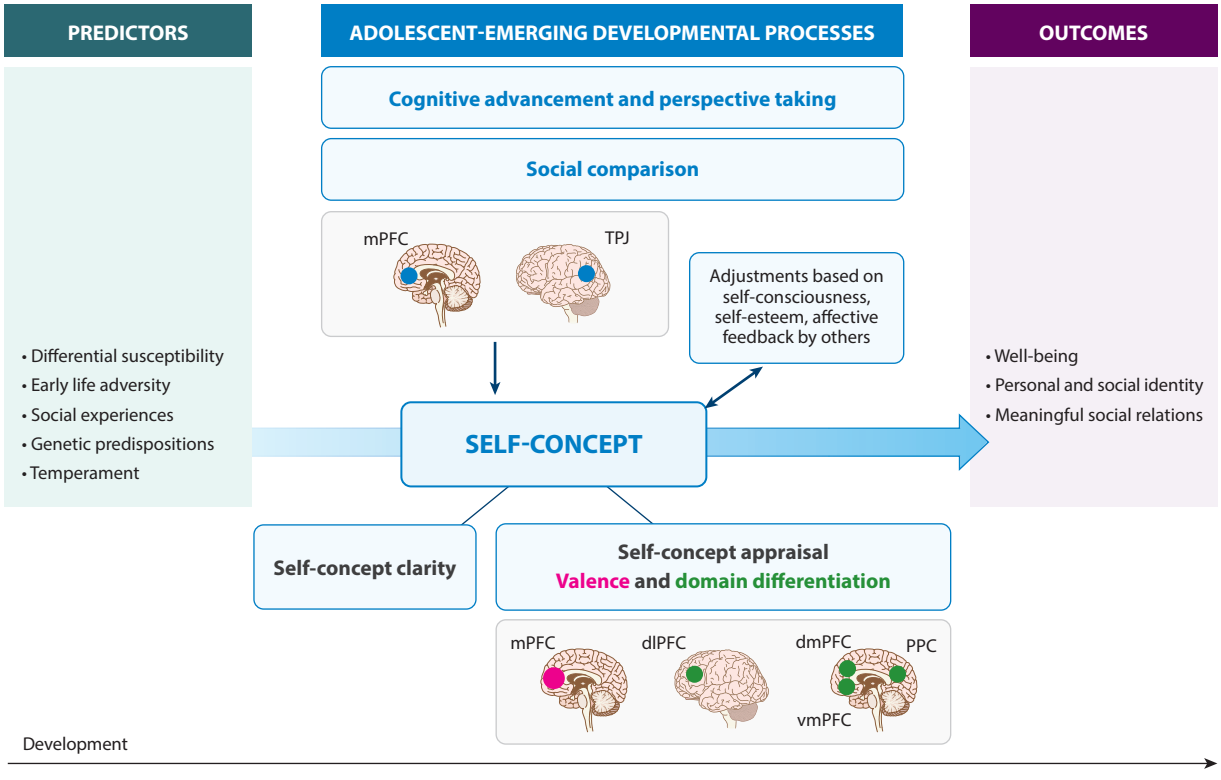

Figure 1

Conceptual model of self-concept development. The model differentiates between predictors, adolescent-emerging developmental processes, and outcomes that are involved in developing a positive and stable self-concept. Abbreviations: dlPFC, dorsolateral PFC; dmPFC, dorsomedial PFC; mPFC, medial PFC; PFC, prefrontal cortex; PPC, posterior parietal cortex; TPJ, temporoparietal junction; vmPFC, ventromedial PFC.

Table 1 Definitions of self-related concepts

Self-concept	Knowledge and beliefs about oneself
Self-concept clarity	The extent to which knowledge and beliefs about the self are clearly and confidently defined, internally consistent, and temporally stable
Self-appraisal	The nonobservable, estimated qualities of the self. It comprises what we do and how we appear based on concrete descriptions of our traits ("I am attractive") rather than objective facts ("I have blue eyes"). Self-appraisal can differ between domains [e.g., academic, physical appearance, and (pro)social].
Self-evaluations	Evaluations of whether or to what extent positive and negative traits fit the self
Direct self-concept	The knowledge and beliefs one has about oneself
Reflected self-concept	The perceived opinions (knowledge and beliefs) of others about the self.
Self-esteem	The overall evaluation or feeling of one's worth or value as a person.
Self-consciousness	Heightened attention to both exterior and interior aspects of the self, often invoking self-conscious emotions such as embarrassment, shame, pride, or guilt.
Self-awareness	The capacity of becoming the object of one's own attention.
Self-regulation	The many processes by which the human mind exercises control over its functions, inner states, or responses.
Identity	One's sense of the person one really is, including subjective feelings of sameness and continuity across contexts and time.

In literature about the self, many different terms are used for concepts that closely resemble one another, such as self-concept, self-esteem, self-knowledge, self-evaluation, identity, and self-concept clarity. Often these terms are used differently across studies or are even used interchangeably within a study. Therefore, in this table we provide distinctive definitions for all these concepts related to self.

traits, or self-evaluations, can be approached from one's own perspective (direct self-evaluations; "I am smart") or another's perspective (reflected self-evaluations; "others think about me that I am smart") (Pfeifer et al. 2009). Finally, self-evaluations can describe traits of the self in different domains, such as academic ("I'm a fast learner"), physical appearance ("I am attractive"), social ("I am kind"), or prosocial ("I'm helpful to others") (Jankowski et al. 2014).

Between ages 9 and 25, self-evaluations generally become less positive and more differentiated across domains (Harter 2012). Adolescents are generally most positive about their social and prosocial traits and least positive about their academic traits. Across domains, but especially in the academic domain, positivity about self traits dips in mid-adolescence (Van der Cruijsen et al. 2018). These findings have been interpreted as a transition from a positivity bias to a more realistic view and from more general to more domain-specific self-evaluations (Van der Aar et al. 2018). Self-evaluations also become more aligned from a reflected and direct perspective, which has been interpreted as indicating that personal self-evaluations become more integrated with social evaluations during adolescence (Van der Cruijsen et al. 2019b). Self-appraisal differentiation and self-concept clarity are, together, regarded as cognitive aspects of the self (Diehl & Hay 2011, Pilarska 2016).

Related to but distinct from self-concept are self-esteem and self-consciousness. Self-esteem indicates the general feeling of one's worth or value as a person (Harter 2012, Rosenberg 1986). It is therefore broader, less specific, and more affective compared with self-concept clarity and self-appraisal. Some studies show that self-esteem dips in mid-adolescence (Harter 2012, Robins & Trzesniewski 2005, Robins et al. 2002), but others report stability during adolescence and increases after mid-adolescence (Orth et al. 2018). Like self-esteem, self-consciousness is a social-affective form of self-awareness (Duval & Wicklund 1972) characterized by heightened attention to exterior and interior aspects of the self (Davis & Franzoi 1999, Fenigstein et al. 1975). Self-conscious feelings can be accompanied by self-conscious emotions, such as embarrassment, shame, pride, or

guilt. Self-consciousness and self-conscious emotions peak in mid-adolescence (Rankin et al. 2004, Somerville et al. 2013). It has been suggested that self-esteem and self-consciousness may serve as interpersonal monitors that influence how social experiences are integrated with our self-concept (Leary et al. 1995, Onoda et al. 2010).

1.2. Processes Driving Self-Concept Development Across Childhood and Adolescence

Driving factors behind self-concept development include cognitive advancements, perspective taking, and social comparison (Pfeifer & Peake 2012, Rapee et al. 2019). Perspective taking allows us to integrate the (perceived) perspectives of others about the self with our own perspectives about ourselves across time and domains. With the rapid developmental increase in higher-order cognitive processes in general (Crone & Steinbeis 2017) and perspective-taking abilities in particular (Blankenstein et al. 2019, Dumontheil et al. 2010), adolescents replace one-dimensional views of themselves with more cognitively complex constructs, which can lead to contradictions in self-views (Van der Aar et al. 2018) but also to more differentiated views of the self, depending on the social context (Harter 2012). Social comparison (comparing the self to others), in contrast, may lead to more intensified social-affective responses to self-evaluations (Rapee et al. 2019, Somerville et al. 2010). In the sidebar titled From Temporal to Social Comparisons, we describe how children develop from using mainly temporal comparisons to using social comparisons (Harter 2012).

These developmental processes influencing adolescent self-concept (perspective taking and social comparison) have separate trajectories and develop in interaction with each other. That is, increasing perspective-taking abilities and heightened susceptibility to the opinions of others about the self may increase the ability and tendency of adolescents to think about the opinions that others may have of the self (Pfeifer & Peake 2012) and to compare themselves to others (Burtzer & Kuiper 2006). Adolescents may realize that there is a broad audience that can observe and evaluate them, which can lead to the feeling of being constantly watched and judged by others [also described as the imaginary audience (Harter 2012, Schwartz et al. 2008)]. This can result in heightened self-consciousness (Rankin et al. 2004, Somerville et al. 2013), which may make self-appraisal temporarily vulnerable but may also be beneficial in the long term. That is, self-consciousness can

FROM TEMPORAL TO SOCIAL COMPARISONS

An intriguing question that has puzzled scientists for centuries is how we develop our self-concept in a social world. According to the influential book *The Construction of the Self* by Harter (2012), young children already have a general sense of self, but self-concept gets more complex and multifaceted during adolescence. For example, young children may describe themselves based on concrete descriptions of their appearance or behavior ("I am tall"), whereas adolescents describe themselves using abstract character traits that can differ across social contexts ("I am a friendly person at school, but at home I'm not always that nice"). Young children are generally overly positive about themselves, partly because adults are generally very positive toward young children ("You did such a great job!") and because young children engage in temporal comparisons. That is, they compare their skills and capabilities now to their skills and capabilities in the past. Since young children learn fast, they can easily conclude that they are better at, for example, drawing, writing, or running than they were before. When children reach puberty, temporal comparisons are increasingly substituted by social comparisons, that is, comparing one's own traits to those of others, which leads adolescents to realize that they are not always the best at everything. Therefore, self-concept becomes more negative but also more realistic between early childhood and adolescence.

lead to more socially acceptable behavior, and the emphasis on social comparisons can lead to more detailed self-concept clarity (Sebastian et al. 2008, Somerville et al. 2013), both of which can lead to enhanced evaluation of the self by others.

Increasing social comparison can also lead to increases in susceptibility to peers' opinions and thereby influence self-concept. Early adolescents, for example, internalize rejection by peers and feel worse about themselves after rejection (Rodman et al. 2017). Additionally, mid-to-late adolescents were found to be more negatively affected by social comparisons and relatively more negative about themselves in direct self-evaluations as compared with early adolescents (Van der Aar et al. 2018). When and how these interactive processes develop has been the core question in research on self and identity formation in adolescence (Branje et al. 2021, Schwartz et al. 2012).

1.3. Outline of This Review

Even though there is great, longstanding interest in self-concept development in adolescence, it has been difficult to measure because self-concept is a highly complex construct that is not directly observable in behavior, and self-report is sensitive to response bias. In the past few years, it was discovered that self-related thoughts can be assessed robustly using neural responses to self-related cues by applying brain imaging techniques (Sebastian et al. 2008), which can be an important additional method for examining self-concept changes (Pfeifer & Peake 2012). Advances in brain imaging research have allowed for empirical investigation of self-concept processes by relating neural activity to self-concept evaluations, self-consciousness, and social feedback.

This review integrates research on self-concept development in adolescence based on a neurodevelopmental model that aims to explain the multiple outcomes of self-concept development in adolescence, such as a more integrated but also more domain-specific self-concept. First, in Section 2, we focus on the general developmental pathways of self and social brain regions in adolescence. Second, in Section 3, we summarize insights from experimental paradigms that examine self-concept development from childhood to young adulthood using functional neuroimaging. Third, in Section 4, we describe several environmental factors that affect self-concept development, including the effects of adversity and social enrichment (i.e., training) on self-concept and brain development. Together, these studies highlight that adolescence is a sensitive period in life for developing a stable and positive self-concept.

2. BRAIN DEVELOPMENT

A recent and novel approach examines self-concept development from a developmental neuroscience perspective. Neuroscience research indicates that adolescence is a sensitive period in terms of brain development, and such research can help to unravel the (interactive) changes of self-concept development (Blakemore & Mills 2014). In this section, we describe why we consider adolescence a formative period in development based on structural brain development studies. Then, we describe conceptual models of brain development and self-concept development. Finally, we suggest a novel perspective based on the processes outlined in the introduction as a working model.

2.1. Structural Brain Development

Until the late 1990s it was assumed that brain development was complete before adolescence, whereas it is now well known—based on two decades of research—that separate brain regions develop structurally with different trajectories until the early twenties. These studies have made use of longitudinal brain imaging designs using magnetic resonance imaging (MRI) to test the postnatal growth spurts in cortical and subcortical neural development. The first growth spurt

takes place in the first 4–5 years of life, during which gray matter, which is composed of neurons, glial cells, dendrites, synapses, and blood vessels, increases (Gilmore et al. 2018). A second growth spurt takes place in the teenage years, during which gray matter decreases, leading to stability of neural density in the mid-twenties (Tamnes et al. 2017). Subcortical brain development follows a more variable pattern of changes compared with cortical development and is at least partly driven by pubertal development (Goddings et al. 2014, Wierenga et al. 2018). White matter tracts, which are thought to be the information transmission properties that connect different cortical regions, develop over the life span. In particular, the uncinate fasciculus, a long-range association pathway between the anterior temporal lobes/amygdala and the orbitofrontal cortex, develops into the third decade of life (Olson et al. 2015).

The reduction of gray matter is thought to reflect an increase in specialization in the adolescent brain related to a decrease in synaptic connections (Casey et al. 2005). Gray matter development has been dissociated in gray matter thickness and surface area, which differ with respect to their pattern and timing of development (Wierenga et al. 2014). The most protracted development has been observed in the lateral and medial prefrontal cortex (mPFC) and the association cortices in the brain, including the temporoparietal junction (TPJ) and superior temporal sulcus (STS) (Mills et al. 2014, Tamnes et al. 2017). The mPFC is the medial region of the most anterior part of the brain, which was the latest to develop evolutionarily (phylogenetic changes) and undergoes tremendous changes in terms of gray matter development during childhood and adolescence (ontogenetic changes) (Amodio & Frith 2006, Blakemore 2008). The mPFC, TPJ, and STS regions together are also known as the social brain regions as they are consistently activated when individuals are involved in mentalizing or thinking about perspectives of others (Blakemore 2008).

The pronounced changes in the second decade of life (Tamnes et al. 2017) suggest higher susceptibility to environmental experiences at this age (Crone et al. 2020). A prior study including 7-to-9-year-old twins investigated the effects of heritability, shared environment, and unique environment on social brain region development. By comparing monozygotic and dizygotic twins, it was possible to estimate the relative contributions of genetics, shared environment, and unique environment on brain structure. The study showed that most brain indices were genetically driven, consistent with prior studies (Jansen et al. 2015). However, the TPJ, a region often implicated in perspective taking, showed a relatively large influence of shared environment (Van der Meulen et al. 2020). In addition, a prior longitudinal study in adolescents showed that structural development in the social brain, especially the mPFC, was correlated with social experiences, specifically changes in friendship quality (Becht et al. 2020). Together, these findings suggest that brain development of regions involved in self-concept and social reasoning is at least partly shaped by environmental factors, such as social experiences.

2.2. Neural Models of Self-Concept Development

Prior influential models of adolescent brain development [such as the imbalance model and the social information processing network (SIPN) model (Casey 2015, Nelson et al. 2016)] have argued that social information processing results from interacting neural nodes, which develop at different rates during adolescence. Given that self-concept is inherently intertwined with all the choices and decisions we make in daily life, it is important to understand the interplay between neural changes related to self-concept and neurodevelopmental changes in social processes that develop during adolescence. In the SIPN model, the affective node, including the amygdala and ventral striatum, processes the emotional significance of (social) stimuli and influences the behavioral and emotional responses to such stimuli. This node is particularly active in early-to-mid-adolescence (Silverman et al. 2015), possibly under the influence of gonadal hormones (Goddings et al. 2019). Pubertal development is thought to instigate a transition period in brain development such that regions

important for social reorientation (adapting to increasing social demands from the environment) become tuned toward processing evaluations of the self. The cognitive-regulatory node, including the dorsolateral PFC and the TPJ, has been implicated in cognitive control, theory of mind, and perspective taking (Casey 2015). This node is thought to have a more linear developmental trajectory and also contributes to self-concept development (Crone & Fuligni 2020, Pfeifer & Peake 2012).

Pfeifer & Peake (2012) were the first to describe a neuroscience model of self-concept development, suggesting that the onset of puberty marks a turning point in how adolescents evaluate themselves by developing more relationships with peers and becoming more sensitive to the social-emotional context. Therefore, purely cognitive perspectives of self-concept become enriched by more diversification of social-emotional perspectives of one's self-concept. Their model distinguishes between three brain networks. First, self-concept is developed by autobiographical memories, which consist of knowledge of general and person-specific experiences in one's life ("Who am I?"). These autobiographical memories rely on the midline structures mPFC and posterior parietal cortex (PPC) (Lou et al. 2004, Svoboda et al. 2006). Second, self-concept can be evaluated along more cognitive and affective-motivational dimensions, which may be associated with more dorsal versus ventral axes of activation in the mPFC. That is to say, the dorsal mPFC is presumed to be involved in more social-cognitive aspects of self-concept, such as certainty about whether evaluation of attributes (e.g., sportive, intellectual, lazy) is related to self (Moran et al. 2006). The ventral mPFC, in contrast, is thought to be involved in the more social-affective aspects of self-concept, such as when ascribing positive or negative attributes to the self or when receiving feedback from others about being liked (Denny et al. 2012, Moran et al. 2006, Somerville et al. 2006). The role of the ventral mPFC has been interpreted as reflecting the valuation of or relevance to the self (D'Argembeau 2013). Therefore, the ventral mPFC–subcortical network is hypothesized to be a crucial network involved in the rise in self-evaluative emotions during adolescence. Third, social comparison aspects of self-concept may rely on perspective-taking and theory-of-mind processes that are associated with a third network in the brain, the TPJ and STS. The latter processes are assumed to be implicated in the reflected aspects of self-concept ("What do others think of me?") (Pfeifer & Peake 2012, Sebastian et al. 2008).

Whereas prior influential models were important for offering descriptive explanations for neural activity patterns in adolescence (i.e., when changes take place), there has been less emphasis on the question of which predictors moderate individual differences (for whom changes take place), which processes are shaped during adolescence (how changes take place), and what the long-term developmental outcomes are (why changes take place). First, in **Figure 1**, we propose that early life experiences (e.g., adversity), differential susceptibility to the environment (e.g., genetics and temperament), and early social experiences (e.g., peer interactions) moderate the behavioral and neural developmental processes that are involved in self-concept development in adolescence. Second, we suggest that two important processes—cognitive advancements, including perspective taking, and social comparison—influence (i.e., mediate) self-concept. Perspective taking is thought to facilitate the development of domain-specific self-concept in adolescence and the integration of reflected and direct self-concept, whereas social comparison is thought to facilitate balancing between perspectives toward the self and others. Together, these processes are thought to be important for positive developmental outcomes, such as personal well-being, developing a stable identity, and achieving positive and meaningful social relationships. As such, the model has strong connections with research into identity, which can be defined as one's sense of who one really is, including subjective feelings of sameness and continuity across contexts and time (Branje et al. 2021).

In the following section, to evaluate and validate the proposed model, we summarize developmental imaging studies that have been conducted to examine self-concept in adolescents.

3. DEVELOPMENTAL PROCESSES AND FUNCTIONAL NEUROIMAGING

Based on research in adults, there is now converging evidence from functional neuroimaging studies for a crucial role of the mPFC in self-evaluations (Denny et al. 2012). The mPFC has many connections with other regions in the brain and is known for its crucial role in thinking about other people's mental states and thinking about oneself in the past, present, and future (Amodio & Frith 2006). Recent neuroscience studies in adolescents have shown that different components of self-concept can be reliably assessed using functional neuroimaging, showing domain-dependent changes within the mPFC in relation to processing self-evaluation and connections with other cortical and subcortical brain regions (Pfeifer & Peake 2012). In the subsequent sections, we summarize research in three areas related to self-concept development and with involvement of the mPFC: self-evaluations, self-consciousness, and feedback of others on self. **Supplemental Table 1** describes the summarized studies in more detail, and **Figure 2** presents a summary overview of activations in the mPFC for various types of self-related processes that are discussed in the subsequent sections.

Supplemental Material >

3.1. Self-Evaluation Studies

Self-evaluations have been studied using experimental tasks that ask participants to rate whether a certain trait describes them well. Functional magnetic resonance imaging (fMRI) designs are strongly dependent on how we define contrasts between conditions (Church et al. 2010). Here, we describe developmental patterns of activation in the mPFC for evaluating self traits in comparison with traits of others (**Figure 2*a***; Section 3.1.1), evaluating self traits in comparison with nonsocial control conditions (**Figure 2*b***; Section 3.1.2), and evaluating the positive and negative valence of self traits (**Figure 2*c***; Section 3.1.3).

3.1.1. Direct self-evaluations compared with other-evaluations. A first set of smaller pioneering studies examined the role of the mPFC for processing self traits relative to traits of others. First, Pfeifer et al. (2007) asked 9-to-11-year-old children ($n = 12$) and adults ($n = 12$) to rate social and academic attributes in relation to the self and to an imaginary other (Harry Potter). Similar to adults, children showed increased activation in the dorsal mPFC when processing information about self > other, but this activation was larger in the 9-to-11-year-old children than in adults. Second, in a longitudinal study including participants who were tested at the ages of 10 and 13 years ($n = 27$), Pfeifer et al. (2013) confirmed activation in mPFC for self > other. They also found that pubertal timing was a predictor for change only in the ventral part of the mPFC and for striatum activity (over and above age), possibly suggesting that puberty is a driving factor in affective forms of self-evaluation development. Subsequent studies in early adolescents (11–14 years, $n = 66$; van Buuren et al. 2020), in early-to-mid-adolescents (10–17 years, $n = 90$; Cosme et al. 2022), in mid-adolescents (14–16 years, $n = 41$; Romund et al. 2017), and in late adolescents and young adults (18–19 years, $n = 37$, and 23–25 years, $n = 36$; Veroude et al. 2014), all reported mPFC activation for self > other evaluations. Specific others used in these studies were "a dissimilar peer," "Harry Potter," "friends, teachers, and politicians," and "a friend," respectively.

However, not all studies confirmed differences in self > other evaluations. For example, Debbane et al. (2014) did not find increased mPFC activity in 12-to-19-year-old adolescents ($n = 42$) for self > same-sex best friend. However, the reversed contrast (other > self) resulted

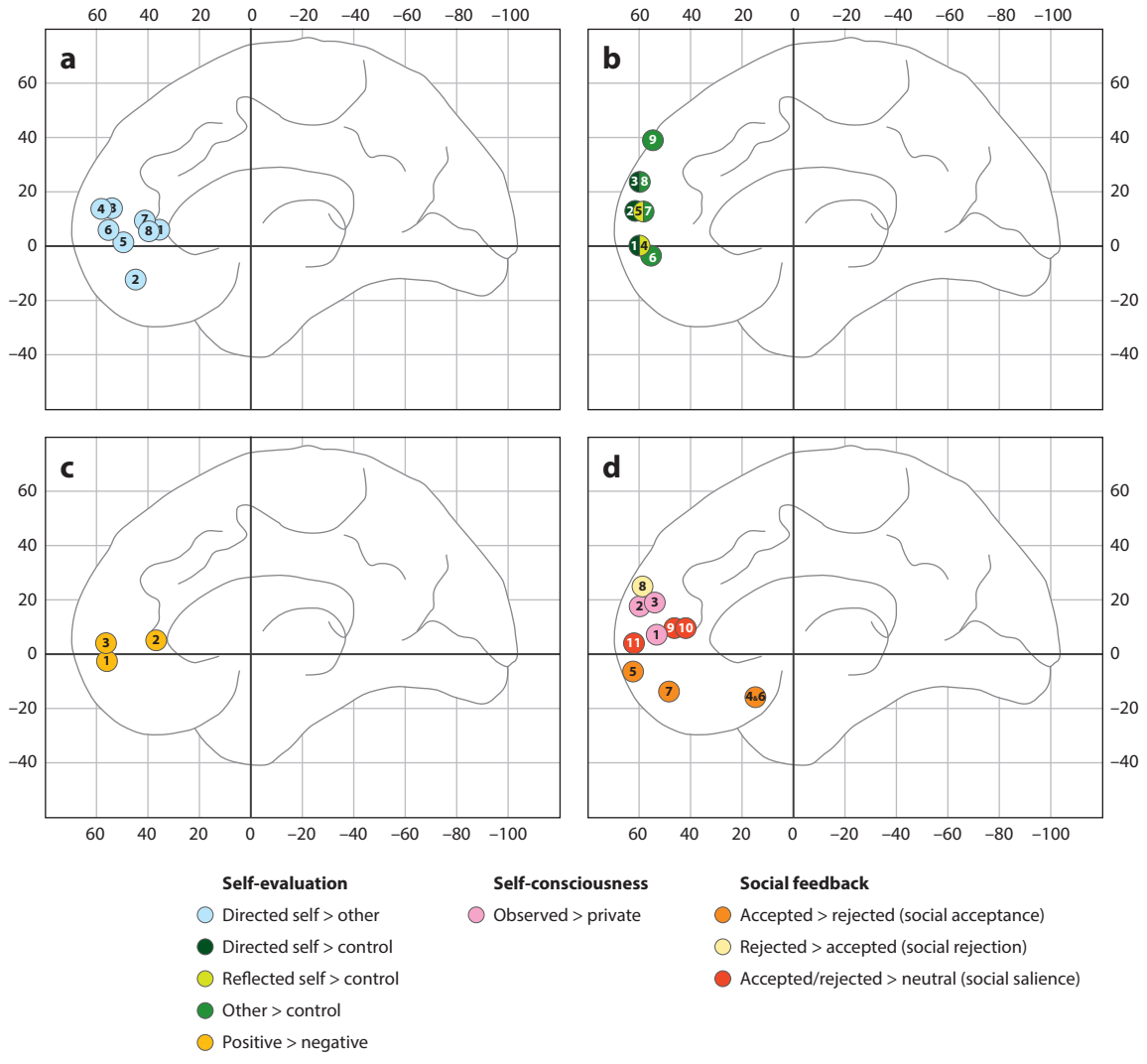

Figure 2

Montreal Neurological Institute (MNI) coordinates for reviewed developmental fMRI studies on self-concept. (*a*) Activation in the mPFC in studies that include direct self-appraisals relative to evaluating traits of others. (*b*) Activation in the mPFC in studies that include direct self-appraisals, reflected self-appraisals, and appraisals of traits of others, contrasted to a nonsocial control condition. (*c*) Activation in the mPFC in studies that include self-evaluations of positive versus negative traits. (*d*) Activation in the mPFC in studies that include social consciousness (*pink*) or social feedback to personal profiles. The latter is differentiated between social acceptance, social salience, and social rejection. The number labels in the colored dots correspond to the study numbers listed in **Supplemental Table 1**, which provides an overview of the included studies. Abbreviations: fMRI, functional magnetic resonance imaging; mPFC, medial prefrontal cortex.

Supplemental Material >

in activation in the ventral mPFC. In two studies including adolescents (11–21 years, $n = 143$; Van der Cruijsen et al. 2019a) and young adults (20–24 years, $n = 30$; Van der Cruijsen et al. 2017), we did not observe significant activation in the mPFC for the contrast in evaluating traits of self > evaluating traits of mothers. Together, these findings might indicate that mPFC activation

is observed only when comparing the self to a relatively distant other, whereas close others (such as best friends and mothers) may be more integrated with one's self-concept.

3.1.2. Direct self-, reflected self-, and other-evaluations compared with a control. Some studies have argued that evaluating the self and others can be studied better relative to a control baseline task that does not involve another person. First, van Buuren et al. (2020) tested neural activation in response to direct self-evaluations and evaluations of both similar and dissimilar others relative to a control baseline task where participants had to indicate whether a given trait contained the letter "a" (11–14 years; $n = 66$). Second, Veroude et al. (2014) asked older adolescents (18–19 years; $n = 37$) and young adults (23–25 years; $n = 36$) to evaluate their traits from their own perspective (direct self) and the perceived perspective of a friend (reflected self) and to evaluate their friend's traits (other). The control condition entailed indicating whether a trait was positive or negative. Third, Barendse et al. (2020) had female participants (10–13 years; $n = 143$) evaluate direct self traits relative to a control condition in which participants indicated whether a certain trait was malleable (yes/no). Fourth, in the Leiden Self-Concept Study (see the sidebar titled The Leiden Self-Concept Study), we examined self-evaluations from the direct-self perspective and from the perceived perspective of unknown peers (reflected self) in adolescents (11–21 years; $n = 150$). Additionally, participants evaluated their mother's traits (other). The control condition entailed categorizing trait sentences into categories (Van der Cruijsen et al. 2018; Van der Cruijsen et al. 2019a,b).

In all four studies, contrasting the test conditions separately against the control condition resulted in highly similar activation in the mPFC. Van der Cruijsen et al. (2019b) observed a linear developmental increase in mPFC activity between ages 11 and 21 for direct self-evaluation but only for the physical appearance domain. The studies further demonstrated that evaluations of distant or unknown others resulted in the activation of relatively dorsal parts of the mPFC (see **Figure 2*b***).

THE LEIDEN SELF-CONCEPT STUDY

The Leiden Self-Concept Study aims to examine the changes in self-concept development in adolescence. The project includes (*a*) an accelerated longitudinal design with neuroimaging, hormonal, behavioral, and questionnaire measures acquired in three waves across a time window of 5 years; (*b*) a focus study on autism; and (*c*) a focus study on a naturalistic gap year intervention (see **Supplemental Figure 1** for a timeline). We present the full project's metadata in **Supplemental Table 2**.

The goal of the longitudinal study is to examine the processes described in this review [e.g., self-concept clarity, self-concept appraisal (direct and reflected)] and development of associated developmental processes (e.g., perspective taking, social comparison). The key aims of the project are:

1. Combining neural and hormonal development with behavioral development;
2. Creating a longitudinal design allowing for testing between- and within-person change;
3. Taking a multidimensional approach to self-concept development, including individual differences, such as differences in self-esteem or autism traits; and
4. Assessing in detail environmental enrichment factors that may influence self-concept development.

The neuroimaging study was completed before the start of the COVID-19 pandemic. The study had two additional behavioral waves after the start of the pandemic (at 2–3 months and 12–13 months).

3.1.3. Direct compared with reflected self. Another question that was addressed in these studies is whether direct self-evaluations result in stronger mPFC activity compared with reflected (i.e., perceived self-evaluations of others) evaluations.

A pioneering study addressed this question in 11-to-14-year-old adolescents ($n = 12$) and adults ($n = 12$). This study showed that the mPFC is more active when evaluating self traits from a direct rather than a reflected perspective (Pfeifer et al. 2009). However, subsequent studies in adolescents and young adults found more strongly overlapping patterns of neural activation when directly contrasting direct and reflected self-evaluations and suggested that these effects may be partly age dependent (Van der Cruijsen et al. 2019b, Veroude et al. 2014). That is, Van der Cruijsen et al. (2019b) showed that with increasing age, direct and reflected mPFC activity became even more similar, consistent with the behavioral evaluations of the self. Together, these studies suggest that with increasing age, perspectives of self become more aligned with perceived perspectives of others, which is reflected in more similar mPFC activity.

3.1.4. Valence of self-evaluations. Prior studies have also suggested that adolescents are more inclined to assign positive traits to themselves (Van der Aar et al. 2018). Several studies therefore examined self-evaluations for positive and negative traits separately. These studies showed that the mPFC is typically more strongly activated for positive than for negative self-evaluations.

This comparison was addressed in three studies: two including young adults [20–24 years, $n = 31$ (Van der Cruijsen et al. 2017) and 18–30 years, $n = 40$ (Van de Groep et al. 2021)] and a separate study in adolescents (11–21 years, $n = 150$; Van der Cruijsen et al. 2018). In these studies, contrasting activation for evaluating positive versus negative traits consistently resulted in mPFC activation around the $z = 0$ coordinate line (see **Figure 2*c***) in a region that is highly overlapping with that of evaluating self-traits in general (**Figure 2*a***). Participants endorsed positive traits more often than negative traits (Van de Groep et al. 2021; Van der Cruijsen et al. 2017, 2018), and activation in this mPFC region was stronger for traits rated to be important to have than for traits rated to be important not to have, regardless of valence (Van der Cruijsen et al. 2017).

Age comparisons in the valence distinction did not result in developmental differences in the mPFC. However, using whole-brain analyses, we found that the ventral striatum was similarly activated by positive and negative traits in mid-adolescence, whereas children and adults recruited this area more for positive traits (Van der Cruijsen et al. 2018). Another study observed that adolescents, but not children and adults, recruited the ventral striatum more for reflected self-evaluation from a friend perspective (Jankowski et al. 2014). These findings may indicate that mid-adolescence is associated with stronger value given to both positive and negative traits, although this question should be addressed in more detail in future studies (Telzer et al. 2022).

Together, these studies demonstrate that self-evaluations relative to distant others and relative to control conditions result in overlapping activation in the mPFC. This activation is stronger for positive valence items, suggesting that mPFC activation during self-evaluations may reflect self-relevance, personal value, or significance to the self (D'Argembeau 2013).

3.2. Self-Consciousness

Adolescence is known as a period of increased sensitivity to the opinions of others, which may become integrated with the ways adolescents view themselves. As can be seen in **Figure 2*d***, there is strong overlap between activation in areas associated with self-evaluation and with self-consciousness.

An early study focused specifically on self-consciousness in adolescence by having adolescents (8–21 years, $n = 69$) experience being observed through a camera by others while in the MRI scanner. Afterward, participants reported on their embarrassment, which peaked during observation

by others in mid-to-late adolescence (Somerville et al. 2013). A region in the mPFC was activated when being observed by others versus being in private, and this response also peaked in mid-to-late adolescence. These findings are consistent with a study that examined public goods game donations while being alone (private) and while being observed and evaluated by peers. Again, the observation and evaluation by peers were associated with increased activity in the mPFC, although in this study the effect was more pronounced for early adolescents (12–13 years, $n = 30$) relative to mid-adolescents (15–16 years, $n = 31$) (Van Hoorn et al. 2016). Finally, a recent study investigated self-conscious emotion processing in adolescents (11–17 years, $n = 26$). The neurotypical participants, which were part of a larger study on autism, activated a region within the mPFC when estimating others' self-conscious emotions (Jankowski & Pfeifer 2021).

Together, these findings suggest that self-consciousness, defined as being observed by others, relies on the same mPFC brain region as evaluations of the self (see **Figure 2*a–d***).

3.3. Social Feedback by Others

The social-affective component of self-evaluation has been studied not only from the perspective of the self but also by using tasks in which participants received feedback from others about being liked (accepted) or not (rejected). As can be seen in **Figure 2*d***, there is a differentiation in the mPFC for when feedback signals salience and when feedback signals acceptance, the latter resulting in more ventral activation.

Social comparison based on first impressions was initially examined in a social evaluation task (Somerville et al. 2006) where participants first indicated whether they thought they would be liked by another peer in a photograph, followed by receiving actual feedback from that peer. Somerville et al. (2006) found dissociable networks in the brain for incongruency of outcomes, independent of valence [dorsal anterior cingulate cortex (ACC)], versus being socially accepted by others relative to being rejected (ventral mPFC). In subsequent studies it was found that ventral mPFC activity for accepted > rejected feedback correlated with self-esteem, such that lower self-esteem was associated with a stronger response in ventral mPFC for acceptance > rejection (Somerville et al. 2010). These findings were interpreted to suggest that the ventral mPFC possibly has a role in signaling the affective salience of social events.

Several developmental studies used variations of this task to examine neural activity associated with being accepted and rejected across development. One prior study used a similar version of the social comparison task as Somerville et al. (2006) in children (8–10 years), adolescents (12–14 years, 16–17 years), and young adults (19–25 years). A general analysis across all participants revealed increased activity in the ventral mPFC and ventral striatum. Even though there were no direct age differences, the number of voxels for neural activity in the mPFC for acceptance > rejection was largest in 16–17-year-old adolescents (Gunther Moor et al. 2010).

Partly similar results were found in an adapted paradigm, referred to as the social network aggression task. This task has three modifications compared with the original task. First, there was no first phase in which participants indicated whether they thought they would be liked; they immediately received the feedback. Second, the task included a neutral condition in addition to acceptance and rejection feedback. Third, participants were allowed to deliver loud noise blasts following the feedback events. In a study including young adults (18–27 years, $n = 30$) it was found that both acceptance and rejection, relative to neutral feedback, resulted in increased activity in the dorsal mPFC. Only the positive > neutral contrast resulted in additional activation in the ventral striatum (Achterberg et al. 2016; see also Guyer et al. 2012, showing subcortical activity for acceptance > rejection in adolescents aged 9–17 years, $n = 36$). In a separate study including young adults (18–30 years, $n = 40$), dorsal mPFC activity was observed only for the contrast acceptance

> neutral condition (Van de Groep et al. 2021). Even though there are no studies yet on the direct age comparisons, one prior study observed activation in a similar region in the mPFC for acceptance and rejection > neutral, for which a dorsal area was mostly driven by rejection feedback in 7-to-9-year-old children ($n = 385$) (Achterberg et al. 2018). In a subsequent longitudinal comparison study two years later (7–9 years versus 9–11 years, $n = 360$), it was observed that mPFC activation generally increased with age, but this effect was observed for all conditions (Achterberg et al. 2020).

One possibility is that the social network aggression task examined not only social evaluation feedback but also self-protection against negative evaluation (see also Hughes & Beer 2013), as participants were given the possibility to deliver noise blasts to the peers who provided the feedback. This concept of self-protection following social evaluation was examined in more detail by Yoon et al. (2018) in a study including adolescents (10–25 years, $n = 60$) who received feedback on artwork. After receiving feedback from peers, participants could subsequently evaluate the artwork of the participant who delivered the feedback. They found that younger adolescents evaluated others' artwork less favorably after receiving negative feedback on a trial-by-trial basis (i.e., higher learning rates) whereas older adolescents took into account the full history of interactions. Lower learning rates were related to increased activity in the ventral mPFC in a reinforcement learning model, suggesting that the ventral mPFC may protect against responding to immediate negative feedback to avoid a decrease in self-value. In contrast, the more dorsal-rostral mPFC activity correlated with accumulated feedback, possibly indicating that this region is more strongly involved in the integration of social information (see also Dumontheil 2014).

These studies showed that being accepted by peers is associated with more activation in the ventral and dorsal mPFC and the subcortical social-affective network of the brain, including the striatum and amygdala. It is possible that sensitivity to evaluations of others has an impact on how we emotionally evaluate ourselves ("Do others like me?") and our self-esteem.

4. PREDICTORS AND OUTCOMES OF SELF-CONCEPT DEVELOPMENT

The developmental processes of cognitive advancements, perspective taking, and social comparison, together with neural developmental changes, result in most adolescents developing a relatively stable and positive self-concept. However, not all adolescents follow the same pathway. It is still unknown why and how some adolescents are affected harder than others by personal and situational factors that are predictive of self-concept development. More specifically, it is unclear how these predictors interact with one another and whether certain predictors influence the trajectory of self-concept development or instead have a direct influence on developmental outcomes such as well-being, identity, and social relationships.

A prior twin study demonstrated that self-concept development in the social domain specifically was influenced by environmental experiences, whereas self-concept in the academic domain was explained more strongly by genetic influences (van Drunen et al. 2021). It is also possible that individual differences in genetic sensitivity make some adolescents more susceptible to social experiences than others (Ellis et al. 2011). Therefore, an important goal for future research is to understand the influences of the social environment on the pathways of self-concept development. Here, we provide examples of social influences that can impact these pathways.

4.1. Early Life Adversity

Experiences of early life adversity (ELA), such as childhood maltreatment (abuse and neglect), family stress (e.g., parental mental illness, divorce), poverty, and socioeconomic inequity, can

influence well-being, identity, and the formation of healthy social relationships (Healy et al. 2021, Li et al. 2020). While it is well known that experiences of ELA predict clinical symptoms later in life (Green et al. 2010, Lahdepuro et al. 2019), it remains unclear which behavioral and neural mechanisms underlie the links between ELA, self-concept development, well-being, and identity (Zinn et al. 2020).

One possible mechanism is that ELA might lead to lower levels of self-concept clarity, which subsequently lowers well-being. It was shown in a previous study that higher experiences of ELA were indeed associated with lower self-concept clarity, which resulted in a higher likelihood of experiencing anxiety and depression symptoms, loneliness, and life distress in adulthood (Wong et al. 2019). Interestingly, a study in mid-adolescents suggested that having a strong prospective self, which was defined as high levels of future orientation, protected against the relation between ELA and externalizing problems, suggesting that a future-oriented self-concept can also be a resilience factor (Zinn et al. 2020).

Another potential mechanism is that ELA influences neural development in the social brain regions that are associated with self-concept development. It has been shown that childhood poverty can have negative effects on brain development (Blair & Raver 2016). For example, children and adolescents from low-income families were found to have structural differences in terms of gray matter development in the frontal and temporal lobe (Hair et al. 2015). Childhood poverty may alter brain development in regions associated with self-regulation, such as the dorsolateral PFC, ventromedial PFC, and dorsal ACC (Palacios-Barrios & Hanson 2019). Taken together, ELA impacts the development of self-concept, possibly due to influences on children's and adolescents' neural sensitivity to social cues.

4.2. Social Experiences During Adolescence

Social experiences during adolescence may also influence self-concept development. Recent studies have examined how negative self-concept, or an inflated positive self-concept, may predict negative developmental outcomes, such as lower well-being and problems with social relationships, including delinquency.

First, parental attachment relations may impact self-concept early in life but may also still affect self-concept development during adolescence. Parents provide proximity in times of need or presence of threats, and poor attachment relations (e.g., childhood maltreatment) are associated with ascribing more negative attributes to the self (Harter 2012). In our prior research, we observed that mPFC activity for evaluating traits for self and for mothers was more aligned when adolescents were more positive about their mothers (Van der Cruijsen et al. 2019a). Another study reported that the neural response to peer acceptance was reduced in children who experienced longer periods of maternal negative affect, suggesting that the neural response to self-evaluation is sensitive to attachment relations with parents (Tan et al. 2014).

Second, adolescence is also known as a period with a rise in social-emotional disorders. Some of these disorders may have their onset in childhood but may lead to particular vulnerability for self-concept development in adolescence (Rapee et al. 2019) or during the transition from adolescence to (early) adulthood (Taber-Thomas & Pérez-Edgar 2014). We observed that young adults with a childhood-onset history of antisocial experiences who scored higher on psychopathic traits showed less positive self-appraisal in the prosocial domain, but no such relation was observed in the physical appearance domain (I.H. Van de Groep, M.G.N. Bos, L.M.C. Jansen, A. Popma & E.A. Crone, unpublished manuscript). Thus, adolescents seem to incorporate their social experiences into their self-concept as they transition into early adulthood. Moreover, young adults with prior antisocial experiences also showed different neural sensitivity to social evaluative cues. In these individuals, a higher level of antisocial behavior was also associated with more

self-protective aggression in the form of delivering noise blasts after receiving social feedback, which was associated with reduced levels of dorsolateral PFC activity (Van de Groep et al. 2022).

Third, adolescents may be influenced by experiences on social media, which may trigger social comparison (Nesi & Prinstein 2015). In our own research, we showed that high social media use was associated with less difference between direct and reflected self-appraisal and higher mPFC activity for direct relative to reflected self-appraisals (Peters et al. 2021). Social media may specifically result in social comparisons (Crone & Konijn 2018). It was previously found that body image dissatisfaction after exposure to thin models was higher in girls with low self-concept clarity (Carter & Vartanian 2022). We showed in our own research that receiving incongruent peer feedback on judgments of whether bikini models were average in body size or too thin resulted in increased activation in the mPFC and insula, but this effect was higher for girls with low levels of self-esteem (Van der Meulen et al. 2017).

4.3. Self-Concept Training

An important question is whether and how self-concept can become more stable, coherent (self-concept clarity), and positive (self-concept appraisal) through training or social enrichment. One possibility is that periods of stronger focus on self-reflection and personal ambitions, together with positive social experiences, can lead to more positive appraisal of one's personal traits, self-esteem, and self-concept. We performed a preliminary study on self-concept enrichment through a gap year program in 38 adolescents (16–24 years) (Van der Aar et al. 2021). In this study, we included participants prior to starting the gap year, halfway through the gap year (6 months later), and after the gap year (12 months later), along with a follow up measurement after 6 more months (18 months later). The goal was to examine behavioral and neural changes before and after the gap year and the effects on making future-oriented academic and societal commitment choices. The study showed an increase in self-positivity on a self-appraisal task (Van der Cruijsen et al. 2018). In addition, neural comparisons revealed that valuing positive but not negative self-traits was associated with increasing activity in the mPFC over time, showing that mPFC activity is sensitive to social experiences. Finally, time analyses across the four time points were associated with increases in self-concept clarity and self-esteem, demonstrating the dynamic interplay between various forms of self-concept (Van der Aar et al. 2021).

Taken together, the development of self-concept and neural activation depends on not only early life but also adolescence-specific experiences.

5. THE FUNCTIONAL SIGNIFICANCE OF MEDIAL PREFRONTAL CORTEX DEVELOPMENT

In this review we demonstrate that mPFC and the broader social brain regions are critically involved in self-concept development. In addition, experimental studies showed increasing or elevated sensitivity in mPFC in adolescence for self-appraisals (Pfeifer & Peake 2012, Van der Cruijsen et al. 2018) and self-consciousness (Somerville et al. 2013) or more alignment over time in self-appraisals from a direct and reflected perspective (Van der Cruijsen et al. 2019b). Several studies in other social domains have also reported elevated neural activity in the mPFC in mid-adolescence (for a meta-analysis, see Burnett et al. 2011). It is important to note that specific age patterns were dependent on the contrast conditions used.

There is currently no clear explanation for the elevated sensitivity in mPFC activation in mid-adolescence. One possibility is that the observed peak in mPFC activity reflects increased salience of personally relevant information (Cosme et al. 2022, Zamani et al. 2022). Accumulating

evidence suggests that the anterior mPFC may be involved in using self-referential schemas (i.e., knowledge structures) that primarily support the processing and/or updating of abstract, domain-general information about the self (Stawarczyk et al. 2021, Van der Cruijsen et al. 2018, Zamani et al. 2022). Constraining information during evaluation of the self (toward personally relevant, significant, or salient information) might improve the stability, coherence, and positivity of our specific self-evaluations (in a certain situation) and of our self-concept more generally (i.e., the knowledge structure) (Zamani et al. 2022).

An additional intriguing finding is that activity in the mPFC is stronger for the domain that is considered to be more personally relevant (Pfeifer et al. 2009). In our own research, mPFC activation was stronger for social versus academic self-evaluations (van Drunen et al. 2021). Moreover, dorsal mPFC activation, as well as activation in the dorsolateral PFC, was more active in response to appearance evaluations compared with academic and prosocial trait evaluations, with such activity increasing with age (Van der Cruijsen et al. 2017, 2018). Finally, ventral mPFC activation, as well as activity in the posterior cingulate cortex, was more active for evaluations of academic traits versus appearance and prosocial traits, possibly indicating that this network relies more strongly on autobiographical self-concept (Van der Cruijsen et al. 2017). These findings show differentiation within the mPFC for various domains.

6. CONCLUSION

Our self-concept helps us adapt to the complex social world by shaping how we think about ourselves and others, our behavior, and how we can regulate our thoughts, feelings and actions to promote well-being and effective social relationships (Oyserman et al. 2012, Robins et al. 2008). Moreover, how we think and feel about ourselves can facilitate our understanding of others (Mitchell et al. 2005) and protect our self-views and social reputation (Hughes & Beer 2013).

The hypothesis presented here is that mPFC activity is strongly involved in self-evaluations in adolescence. Activation in the mPFC is context-dependent and connects to several other regions outside of the cortical midline to develop domain-specific self-appraisals (differentiation) on the one hand and to balance between direct and reflected self-evaluations (integration) on the other hand. There seems to be consistent evidence that reflected self-evaluation development, which relies strongly on perspective-taking development, is related to increasing engagement of social brain regions, including the TPJ (Carter & Huettel 2013). Thus, the dorsal mPFC–TPJ–STS network may be a crucial network involved in reflected self-appraisals, self-consciousness, and balancing self and others (Mars et al. 2012).

Developing a stable concept of self is strongly intertwined with developing social relations with family, friends, employers, and other citizens. People growing up in the current time face several high-stakes global and societal challenges, including the recent pandemic crisis and increasing socioeconomic inequity during opportunities for optimal development (Orben et al. 2020). It is urgent to identify how the current generation of young adolescents navigates these rapidly changing social worlds and what the predictors for positive developmental outcomes are. Creating positive circumstances for more optimal self-concept development can have positive results on well-being, identity, social relations, and, ultimately, life choices such as academic success and social well-being.

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