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THE NEURAL FOUNDATIONS OF EVALUATIVE SELF-KNOWLEDGE IN MIDDLE CHILDHOOD, EARLY ADOLESCENCE, AND ADULTHOOD

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The self has been an object of scientific curiosity for decades in psychology, and many centuries longer in philosophy. During that time research has arguably emphasized the study of mature self-concepts, but the developing self has become an important topic as well—in part due to the association between self-concepts and critical developmental outcomes such as psychological well-being, academic achievement, or engagement in risky behavior (Harter, 1999). Naïve developmental theories about the self abound, such as the expectation that babies are essentially lacking in self-knowledge while teenagers are preoccupied with the self—despite research suggesting adolescents are neither completely self-absorbed nor without reason for their enhanced self-focus (Vartanian, 2000), and infants are self-aware to some extent (Meltzoff & Moore, 1977). But how, indeed, do we come to possess a self that

organizes, guides, and motivates our expectations and behaviors? This question can be asked on many levels, such as how perceptions of oneself develop in context (at home, at school, across cultures) or what kind of mental representations of the self can be held by children of different ages. A relatively new approach afforded by technology, under the banner of "developmental social cognitive neuroscience," examines the neural systems supporting the uniquely human capacity for personal identity throughout development.

In this chapter we focus specifically on change in the brain regions associated with processing representations, descriptions, or perceptions of oneself ("Who am I? What are my likes and dislikes?"). We subsequently will refer to these phenomena as evaluative self-knowledge or self-evaluations (see Harter, 1999). This focus excludes many other aspects of self-related processing, such as self-recognition or visual self-awareness; self-control or self-regulation; and agency or self-generated actions and intentions. Recent neuroimaging work is beginning to address the neural systems supporting these phenomena as well (for a review, see Lieberman, 2007), but here we emphasize the significant and independent body of research that has examined the process of reflecting on the self's attributes, abilities, and preferences. In the following section, we briefly describe the functional importance and development of evaluative self-knowledge. We next review relevant developmental and social cognitive neuroscience research addressing three aspects of self-evaluations: general evaluative self-knowledge, domain-specific self-concepts, and taking the perspective of others on the self. The chapter concludes by proposing a developmental model of the neural systems supporting self-evaluations and discussing promising directions for future research. We propose that taking a developmental social cognitive neuroscience approach to the self may help to provide new insights about the social or cognitive sources and mechanisms of self-development in typically developing children, biologically rooted justifications for the powerful effects of self-concepts during development, and foundations for understanding social developmental disorders associated with atypical self-perception, such as autism spectrum disorders (ASD).

FUNCTION AND DEVELOPMENT OF EVALUATIVE SELF-KNOWLEDGE

One way to begin our account of evaluative self-knowledge development is with the global sense of worth we ascribe to ourselves, also

known as self-esteem. Very early in childhood, children do begin to exhibit individual differences in self-esteem that manifest themselves in aspects of behavior, such as confidence and independence, but it is not until middle childhood that behavioral representations of self-esteem become grounded in competence and skills across contexts to form a hierarchically organized self (Haltiwanger, 1989; Harter, 1990a; Harter, 1999). For example, part of how I feel about myself as a person may be determined by my self-evaluations in the academic domain, which is a function of additional subordinate self-concepts in multiple disciplines (math, science, reading, etc.). The importance of various domains to the self was proposed over a century ago to weight the relative contribution of such evaluations towards global self-esteem (James, 1890); for example, if I do not value academic abilities at all, my lack thereof will trouble me little and have a trivial negative impact on my self-esteem, if any.

Critically, however, a domain-specific self-concept contributes not only to global self-worth to the extent it is valued, but also specifically to outcomes in that domain. Developmental psychologists have thus charted the consequences and trajectories of positive and negative self-concepts in various contexts (for reviews, see Bracken, 1996b; Damon & Hart, 1988; Harter, 1999; Marsh, 1990b, 1990c; Rosenberg, 1979; Wigfield et al., 1997). For example, a child who holds negative views of his or her abilities and attributes in a given academic domain receives lower grades on average than children with positive self-concepts in that domain, even after accounting for prior academic performance in that domain (Marsh, 1990a).

Most evidence suggests self-concepts in primary domains (like academics, athletics, physical appearance, behavioral conduct, and sociability) solidify during the transition from childhood to adolescence, even though evaluative self-knowledge may be differentiated to some degree as early as 5 years of age (Crain, 1996; Wigfield et al., 1997). Across multiple measures, average correlations between domain-specific self-concepts have been shown to decrease in both cross-sectional and longitudinal assessments during childhood and adolescence (Harter, Bresnick, Bouchey, & Whitesell, 1997; Marsh, 1990b, 1990c; Marsh & Ayotte, 2003; Marsh, Craven, & Debus, 1999). In other words, early views of the self are relatively dominated by valence rather than actual domain-specific content; children who believe they are smart are also highly likely to also believe they make friends easily, are good at sports, and so on. With increasing age, domain-specific self-concepts also become more stable and closely aligned with external indicators (e.g., higher correlations appear between academic self-concepts and

grades, while correlations between other domain-specific self-concepts and academic outcomes drop, as do those between academic self-concepts and outcomes pursuant to other domains; Marsh, Craven, & Debus, 1998; Wigfield et al., 1997).

In any given domain, research has suggested the self-concept is populated by relevant trait descriptions that integrate many instances of behavior with perceived or actual evaluations made by others about our attributes and abilities. The cognitive ability to combine specific behavioral features of the self (I can run fast and throw far) into higher-order generalizations of characteristics that drive behavior (I am athletic) appears in middle childhood, approximately around age eight or nine (for reviews, see Damon & Hart, 1988; Harter, 1999; Rosenberg, 1986). Although a young child may use traits words to describe him or herself, they usually reflect single instances of behavior; there is no evidence that their use is based on abstractions of consistent qualities and recurring behaviors. On the other hand, a teenager might describe herself as popular because she gets invited to many parties, makes friends easily, believes her classmates think she is very well liked at school, and so on. An important point this highlights about self-evaluations is that, in addition to being complex internal cognitive representations, they may also be dependent on what we think others think of ourselves. This general theoretical perspective, also known as symbolic interactionism, proposes that self-concepts develop via the internalization of others' appraisals of us (Baldwin, 1895; Cooley, 1902; Mead, 1934). In this way, close others (and society at large) play a role in shaping our self-concepts, through their evaluations of our attributes and abilities. While family members typically hold the strongest influence over the developing self in childhood, peers occupy an increasingly important position during adolescence (Steinberg & Morris, 2001; Steinberg & Silverberg, 1986). Furthermore, while parents have an important role in fostering academic achievement and values throughout adolescence (Bouchey & Harter, 2005), peers tend to have more influence over social behaviors, views about interpersonal competence, and popularity (Gardner & Steinberg, 2005). Table 8.1 provides a summary description of these various components of self-evaluations, including definitions, examples, and the stage(s) during which a given component may be of particular importance in self-development.

In this chapter, we review developmental and social cognitive neuroscience evidence for the neural foundations of self-evaluations from three perspectives highlighted above. The first and most basic perspective examines the neural correlates of general evaluative self-knowledge. The second point of view explores how the neural representation

Table 8.1 Components of Self-Evaluations

Component	Definition	Example	Focal Periods
Self-esteem	Global sense of self-worth	"I like myself."	Early childhood
General Self-knowledge	Composed of traits that represent higher-order generalizations of recurring behaviors, attributes, or abilities	"I am friendly."	Middle childhood
Domain-specific Self-concepts	Organization of self-knowledge by various contexts	"I am good at science, but bad at sports."	Late childhood–early adolescence
Reflected Self-appraisals	Process of incorporating the perspectives of other individuals about the self, depending on the domain, various evaluative sources may have more influence	"Other kids at school think that I'm popular."	Adolescence

of domain-specific self-concepts may differ from that of general evaluative self-knowledge. The third and final perspective focuses on systems that are engaged in taking someone else's perspective on ourselves, both across and within domains. Figure 8.1 illustrates the brain structures mentioned throughout the chapter that provide critical support for various components of self-evaluations.

The proposed role of each region will be described in greater detail throughout the manuscript, but here we briefly summarize the general functions of each structure of interest. Anterior medial prefrontal cortex (MPFC; putative Brodmann's Area [BA] 10 and 32) has been strongly implicated in self-reflection. So has precuneus and posterior cingulate in medial posterior parietal cortex (MPPC; BA 7 and 31), in addition to its roles in episodic memory and mental imagery. Moving from MPFC up towards the apex of the head along the anterior cortical surface, dorsal medial prefrontal cortex (DMPFC; BA 9 [medially] and 8) is frequently engaged by more general social cognitive tasks including person perception and mentalizing. These functions have also been attributed to a key lateral parietal region known as the temporal parietal junction (TPJ; at the intersection of BA 22, 39, 40), which some have proposed is necessary for theory of mind and perspective-taking. Nearby, posterior superior temporal sulcus (pSTS) may feed primary

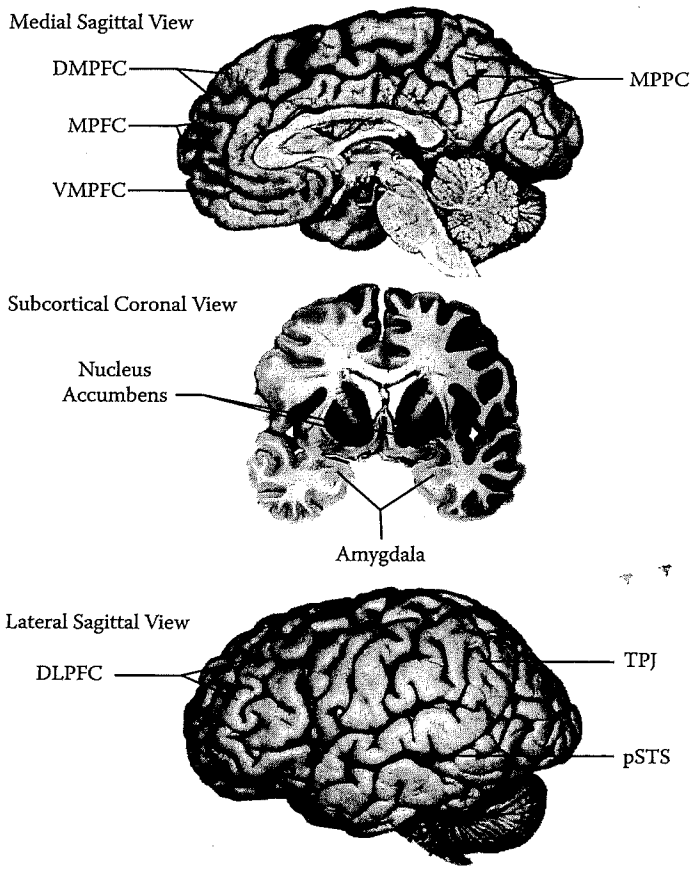

Figure 8.1 Brain regions centrally involved in various components of self-evaluations.

sensory information, particularly that which is relevant to the social domain, to higher-order processing regions. Dorsolateral prefrontal cortex (DLPFC; BA 46 and 9 [laterally]) and the hippocampus (a subcortical structure not pictured) subserve controlled processes of working memory and episodic memory storage. Other important subcortical structures include the amygdala, a site responsible for automatic affective associations and emotional learning, as well as the nucleus accumbens, a region involved in reward and approach motivation. Finally, similar affective, evaluative, and motivational functions are attributed to ventral medial prefrontal cortex (VMPFC; BA 10 and 11 [medially]), which is found by moving from MPFC down along the anterior cortical surface.

NEURAL CORRELATES OF GENERAL EVALUATIVE SELF-KNOWLEDGE

More than a dozen neuroimaging studies of general self-knowledge retrieval have been conducted in adult samples. Collectively, these studies provide a substantial consensus as to the neural systems that are likely to support mature self-evaluations. These studies typically ask adults to respond whether trait words across a variety of domains describe themselves, or assess their personal preferences. Two regions have consistently been associated with this manner of evaluative, self-referential processing: MPFC and MPPC. Such self-knowledge retrieval tasks typically produce relatively greater activity in MPFC and MPPC compared with other social or semantic processes, ranging from reporting on the personality and preferences of friends or famous individuals to making judgments about the visual appearance of words presented onscreen (D'Argembeau et al., 2005; D'Argembeau et al., 2007; Fink et al., 1996; Heatherton et al., 2006; Johnson et al., 2002; Kelley et al., 2002; Lieberman, Jarcho, & Satpute, 2004; Zysset, Huber, Ferstl, & von Cramon, 2002). Relatedly, accessing autobiographical memories and reflecting on them tends to engage putative BA 10 in MPFC (among other regions), while retrieving episodic memories does not reliably do so (for a review, see Gilboa, 2004). An additional fact of note is that MPFC and MPPC possess some of the highest resting metabolic rates in the brain. Activity in these regions tends to transiently decrease during complex, goal-directed tasks that focus participants on external factors, leading some to suggest this pair of cortical midline structures is thus responsible for processing that is internally directed or self-focused, and may provide us with an ongoing sense of one's "self" in relation to one's environment during rest (e.g., Gusnard, Akbudak, Shulman, & Raichle, 2001). Because these regions are often more active during rest than other cognitive tasks, they are often referred to as the "default network," alongside lateral parietal regions including TPJ.

However, several neuroimaging studies have not found that the activity in MPFC or MPPC is unique to self-evaluations (e.g., Craik et al., 1999; Kircher et al., 2002; Ochsner et al., 2005; Schmitz, Kawahara-Baccus, & Johnson, 2004; Vanderwal, Hunyadi, Grupe, Connors, & Schultz, 2008). In these instances, evaluative self-knowledge retrieval and control tasks (like retrieving knowledge about other social targets) typically engage MPFC and/or MPPC to a similar extent. Therefore, it is still debated whether the neural systems supporting self-knowledge processes differ from those supporting evaluations of other people. Growing evidence suggests that the most anterior subregion of MPFC (BA 10 rather than

BA 8 and/or BA 9, which we refer to as DMPFC) is more likely to be recruited to process information about individuals when they are seen as similar to ourselves (Mitchell, Banaji, & Macrae, 2005a; Mitchell, Macrae, & Banaji, 2006). A balanced viewpoint might thus be that although MPFC and MPPC are essential to evaluative self-knowledge, this medial fronto-parietal network may also support our understanding of other people, particularly those with whom we are close.

Building upon this foundation of research, we conducted the first study of the neural correlates of evaluative self-knowledge retrieval processes in a developmental sample (Pfeifer et al., 2007), which suggested that children exhibit both similarities to and differences from the adult patterns described above. We compared 9- and 10-year-old children and young adults completing a scanner task in which participants alternated between retrieving knowledge about themselves or a fictional, familiar other (Harry Potter). The major similarity between children and adults was that each age group engaged dorsal and/or anterior MPFC as well as MPPC during this social cognitive task of retrieving knowledge about oneself and another individual, regions previously shown to be involved in both processes.

Yet we also observed significant differences between children and adults in this study. Activity in anterior MPFC (BA 10 and BA 32) was significantly enhanced in children compared to adults; the BOLD signal was both stronger in amplitude and covered a larger spatial extent in the children. While this region was significantly more active in both children and adults when retrieving self-knowledge than knowledge about Harry Potter, in adults this manifested as relatively less deactivation compared to a resting baseline, but in children evaluative self-knowledge retrieval elicited activity in anterior MPFC above a resting baseline. This may indicate that children engage cortical midline structures less while resting than do adults—perhaps because children are less self-reflective than adults, or possibly because there are developmental changes in the tonic activation of these regions, independent of ongoing mental processes. Recently, a study compared activity in the default network across children and adults (aged 7–9 and 21–31 years, respectively), finding that while the regions involved in the default network were consistent across age groups, the functional connectivity between VMPFC, MPPC, and lateral parietal areas including TPJ is significantly stronger in adults than children (Fair et al., 2008). Nevertheless, this study did not report any significant differences in the absolute level of default network activity in children and adults. How much the development of the default network contributes to changes in the neural systems supporting general evaluative self-knowledge thus

remains an open question for future research. Therefore, if changes in default network activity are not responsible, one alternative explanation for our findings of relatively greater activity in MPFC during self-knowledge retrieval in children than in adults is that self-reflection is qualitatively different across the two age groups.

Finally, in this study and contrary to other studies, both children and adults engaged MPPC more when thinking about Harry Potter's academic and social qualities than their own. Specifically, MPPC was less active during self-reflection than during social knowledge retrieval and a resting baseline. Furthermore, children used more anterior subregions affiliated with mental imagery and perspective taking, whereas adults used more posterior subregions associated with episodic memory retrieval (for a review of functional subdivisions within MPPC, see Cavanna & Trimble, 2006). We theorized this might be due to some particular quality of Harry Potter, a fictional character depicted extensively in movies and books, since this pattern has not been observed in any other studies contrasting self- and social knowledge retrieval (in which the other targets include friends, family members, or famous individuals like politicians). These results may also suggest that adults are less likely than children to retrieve episodic memories when reporting on themselves, perhaps relying on stored semantic knowledge of the traits they possess. Indeed, some evidence for this was observed in that one of the only regions activated more in adults than children during self-knowledge retrieval was lateral temporal cortex (BA 22), a region often implicated in semantic storage (see also Lieberman et al., 2004).

NEURAL FOUNDATIONS OF DOMAIN-SPECIFIC SELF-CONCEPTS

Exploring the neural systems supporting general evaluative self-knowledge, as in the studies described above, is a reasonable first step in developmental social cognitive neuroscience investigations of the self. To further advance this field, however, these inquiries eventually need to take into account the multidimensional nature of the self (Bracken, 1996a). As mentioned in the introduction, domain-specific self-concepts strongly contribute not only to a child's global self-image, but also specifically to outcomes in these domains (Harter, 1999). Strong correlations between self-concepts and relevant behaviors have been demonstrated in a variety of domains, including greater social competence and more peer acceptance as well as less aggression, loneliness, depression, and anxiety (Barry & Wigfield, 2002; Bellmore & Cillessen, 2003;

Berndt & Burgy, 1996); popularity and increased frequency of risky behaviors such as drug or alcohol use (Stein, Roeser, & Markus, 1998); negative body image and greater eating disorder pathology (Hargreaves & Tiggeman, 2002); as well as positive athletic self-concept and greater participation in school sports (Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002). What remains unclear from this line of behavioral research is how—via what mechanism(s)—domain-specific self-concepts exert such strong effects on behavior.

Most neuroimaging research on self-knowledge studies the self in a global sense, representing (and averaging across) a wide sampling of domains, expertise, and evaluations. To our knowledge there have been only two prior studies conducting direct inquiries of whether and how the neural systems involved in self processes differ across domains (Lieberman et al., 2004; Rameson & Lieberman, 2007). This work, unlike others, specifically examined retrieval of self-knowledge by domain. In the first study, adult participants had an abundance of experience in one domain (on average, 10 years) and considered their performance and participation in that domain a central or defining aspect of themselves, while in the other domain they had little experience and/or did not identify strongly with it. Results showed they activated ventral MPFC (VMPFC), nucleus accumbens, amygdala, lateral temporal cortex, and inferior parietal cortex more when retrieving knowledge in high- versus low-experience domains, whereas the reverse contrast led to more activity in dorsolateral PFC (DLPFC; Lieberman et al., 2004). Evidence of schematicity (exhibiting enhanced speed of processing for information in a given domain; Markus, 1977) was also associated with increased activity in MPPC and decreased activity in hippocampus and dorsal MPFC (DMPFC) during self-knowledge retrieval from the schematic domain, relative to the low-experience one. In the second study, adult participants demonstrating schematicity in an athletic domain exhibited more activity while viewing information from that domain versus an academic domain in the nucleus accumbens and the amygdala; furthermore, the response in both structures positively correlated with recall of information from the athletic domain in a surprise test (Rameson & Lieberman, 2007).

These findings support a characterization of the processes involved in low-experience, low-identification domains as "evidence-based" retrieval of self-knowledge, because the neural structures involved (in particular, DLPFC and the hippocampus) are implicated in episodic and working memory. In contrast, the processes involved in schematic, high-experience, high-identification domains may be characterized as "intuition-based" retrieval of self-knowledge, because the active

network of structures is associated with motivation, emotional learning, impulsive behavior, automaticity, and affective reactions. This distinction between evidentiary and intuitive self-knowledge is supported by a series of behavioral and neuropsychological studies conducted by Klein and colleagues (Klein, Loftus, & Kihsltrom, 1996; Klein, Loftus, Trafton, & Fuhrman, 1992; Klein, Rozendal, & Cosmides, 2002) demonstrating that autobiographical evidence is not always necessary to report on one's self. For example, temporarily amnesic patients' judgments about the self-descriptiveness of traits are as accurate as normal controls.

When might schemas—indicating the possession of intuitive self-knowledge—emerge for particular self-concepts in the course of normal development? An intense level of identification with a domain (which actually constitutes a core defining feature of self-schemas; Markus, 1977) could reasonably be expected to appear during the transition between late childhood and early adolescence, as self-concepts in primary spheres like academics or sociality cohere and become more strongly related to subjective task values (Steinberg & Morris, 2001; Wigfield et al., 1997). Indeed, the earliest mentions of potential automatization of domain-specific self-concepts (or equivalently, the presence of self-schemas) surface at this developmental stage (Harter, 1999; Higgins, 1991; Marsh, 1990a; Siegler, 1991; Stein et al., 1998). This is also the time during which identities begin to surface around activities or abilities and "crowds" coalesce at school (e.g., jocks, nerds, and so forth [Brown, 2004]).

To begin examining the neural foundations of domain-specific self-concepts in children, we conducted a study including 52 typically developing 9- and 10 year-olds (20 boys, 32 girls) who completed the same scanner task described above, in which blocks alternated between retrieving knowledge about oneself and Harry Potter (Pfeifer, Dapretto, & Lieberman, in preparation). Critically, some blocks queried academic self-perceptions, and others tapped perceptions of social competence. Several hours after the scan, children completed the Self Perception Profile for Children (SPPC; Harter, 1985). The SPPC includes two subscales assessing academic and social competence, so mean scores on these subscales were calculated for each child and used as regressors.

The primary objective of this study was to see whether strongly positive perceptions of one's competence in a domain (a proxy for identification and experience) moderated patterns of brain activity supporting general evaluative self-knowledge. We found that activity in the amygdala—one of the structures especially strongly implicated in automatic affective associations, motivation, and emotional learning—was greater during

self-knowledge retrieval from a high-competence domain relative to a low-competence domain, increasingly so to the extent children reported more positive self-images in the former domain than the latter ($r(50) = 0.48$, $t = 4.44$). A similar association was also observed in MPPC and DLPFC, two regions involved in episodic and working memory ($r(50)$s = 0.56 and 0.44, ts = 4.78 and 4.15, respectively). This combination of intuitive- and evidence-based systems suggests that children may have been transitioning from general processes of self-knowledge retrieval to expert processes, some of which may function in any high-experience domain, whereas others depend on the presence of self-schemas in a particular domain. Therefore, the overall pattern suggests shifts from evidentiary to intuitive self-knowledge retrieval processes are merely underway and not yet completed in 9- and 10-year-olds, even in basic domains like the ones used here.

Due to computer difficulties while collecting reaction time data, we have yet to determine whether any children also possessed self-schemas in these domains, but as activity in only one automatic and affective structure (the amygdala) was correlated with self-concepts, the neuroimaging data suggest that most children had not yet developed schemas about their relevant abilities or lack thereof. This leads to one practical implication of our findings. Self-schemas are thought to be particularly resistant to contrary information and difficult to change (Markus, 1977)—thus, if 9- and 10-year-old children have not yet developed a self-schema as a social outcast or academic failure, there may still be a good chance of modifying these negative self-perceptions (Brinthaupt & Lipka, 1994). In other words, while typically developing children clearly have the capability to reflect on their personal attributes and qualities at this age, they probably have not yet come to a particularly entrenched viewpoint on the self, even in such common domains as sociality and academics. However, children on average did possess moderately positive views of themselves in both domains, so it remains to be determined whether persistently negative self-concepts correlate with intuitive, automatic, and affective self-knowledge systems this early in development. Such a study would require targeted recruitment of children that possess these negative self-perceptions.

NEURAL CORRELATES OF REFLECTED SELF-APPRAISAL PROCESSES

In the previous sections, we discussed the neural systems supporting general evaluative self-knowledge retrieval, as well as domain-specific

self-concepts. Our introduction pointed out not only how self-knowledge may be shaped by perceptions of how others view the self, but also how family members and peers have varied levels of influence in certain domains across development. In this final subsection, we explore how these facets of self development intersect in the brain via two questions: How do MPFC, MPPC, and other brain regions enable reflected self-appraisals (in other words, taking another individual's perspective on the self) across development, and is this moderated by whose perspective is being taken in a given domain?

To our knowledge, only two previous neuroimaging studies have directly examined the neural correlates of reflected self-appraisals in adults. Findings from these studies overlapped to some degree; both reported a high degree of similarity overall between direct and reflected self-appraisals, and both found that reflected self-appraisals may be associated with more activity in orbitalfrontal and insular cortex (D'Argembeau et al., 2007; Ochsner et al., 2005). Meanwhile, social cognitive neuroscience research more generally suggests four key regions that may also be involved in reflected appraisals. These areas have been emphasized by reviews as cornerstones of mentalizing and other unique aspects of human social cognition, and include temporal-parietal junction (TPJ), dorsal MPFC (DMPFC), posterior superior temporal sulcus (pSTS), and the temporal poles (Frith & Frith, 2006; Frith & Frith, 2003; Saxe, 2006). Third-person perspective-taking processes, such as reasoning about other people's mental contents or beliefs, are thought to rely on a region at the intersection of inferior parietal lobule and posterior superior temporal gyrus, frequently referred to as TPJ (Aichhorn, Perner, Kronbichler, Staffen, & Ladurner, 2006; Apperly, Samson, Chiavarino, & Humphreys, 2004; D'Argembeau et al., 2007; Ruby & Decety, 2003; Samson, Apperly, Chiavarino, & Humphreys, 2004; Saxe & Kanwisher, 2003; Saxe & Wexler, 2005). Mental state attribution and impression formation also typically engages DMPFC (Mitchell et al., 2005a; Mitchell, Macrae, & Banaji, 2005b, 2006). Extracting information about goals and intentions from biological motion within a social context is thought to be a primary function of pSTS (Pelphrey, Morris, & McCarthy 2004; Pelphrey, Viola, & McCarthy, 2004). Finally, the temporal poles may be responsible for storing social and personal semantic knowledge, and linking perceptions with emotions (Olson, Plotzker, & Ezzyat, 2007).

We recently conducted a study including early adolescents (aged 11–13 years) and adults designed to address the two questions opening this subsection. That is, we (a) compared the neural correlates of direct and reflected self-appraisals made by adolescents and adults, and (b) for

adolescents in particular, explored the influence of parents and peers across domains on the networks supporting reflected appraisals (Pfeifer, Masten, Borofsky, Dapretto, Lieberman, & Fuligni, in press). The scanner task was nearly identical to that used in our previous studies, in that we asked about academic and social qualities, but instead of contrasting the self with Harry Potter we also asked participants to tell us what they believed their mother, best friend, and classmates thought about them. We found that in both age groups, making these reflected self-appraisals engaged regions associated with self-reflection (MPFC and MPPC) as well as social cognition and perspective taking (TPJ, DMPFC, and pSTS). Furthermore, adolescents exhibited more activity in MPFC and MPPC when making reflected appraisals in a domain that was consistent with an evaluative source's sphere of influence (i.e., taking a best friend's perspective on the social self, or a mother's perspective on the academic self). Perhaps the medial fronto-parietal network composed of MPFC and MPPC is most sensitive to processing information about ourselves in relation to others, rather than in a context-independent fashion. This suggests that reflected self-appraisals made in a domain where a given evaluative source possesses a high degree of influence may be flagged by our brains as being more self-relevant.

Finally, there was an additional and unexpected discovery made in this study: adolescents also recruited TPJ, DMPFC, and pSTS (in addition to MPFC and MPPC) during direct self-appraisals, whereas adults only engaged MPFC and MPPC. This suggested the possibility that direct self-reflection in teenagers incorporates aspects of reflected appraisal processes. Despite not being asked to consider others' perspectives on themselves, adolescents engaged components of the social perception network commonly associated with doing so (including TPJ, DMPFC, and pSTS), in addition to recruiting the cortical midline structures affiliated with self-reflection and self-knowledge retrieval (in MPFC and MPPC). There are several possible developmental explanations for why direct self-appraisals appeared to possess characteristics of reflected self-appraisals in early adolescence. Perhaps self-appraisals are simply more dependent on what individuals believe others think about the self specifically during this period, as compared with both adulthood (as shown in this study) and childhood (as suggested by our other work discussed above; Pfeifer et al., 2007). However, we did not ask children to make reflected appraisals in the scanner. Perhaps once a task design provides participants with the idea to consider others' perspectives on the self, children are also apt to do so during direct self-reflection, just like adolescents but unlike adults. Or more generally, younger samples may not follow directions as well as adults, and take outside perspectives on the self during direct self-appraisal conditions by accident. Future research should attempt to disentangle these possibilities.

DEVELOPMENTAL MODEL

One can draw at least two conclusions from this brief review of the relevant developmental and social cognitive neuroscience research addressing evaluative self-knowledge. First, although there is a reasonable amount of groundwork that has been laid, there is much work that needs to be done, and as we indicated throughout there are many opportunities for investigators to do so. Perhaps more important, this review demonstrates that typically developing children and adolescents do differ from adults in the neural systems supporting self-evaluations in meaningful ways.

These differences allow us to outline a tentative developmental model in which the brain provides a biological foundation for the self. In this model, children are likely to rely most heavily on the medial fronto-parietal network (MPFC and MPPC) to produce self-evaluations—doing the mental "work" involved in defining the self via traits that are abstracted from episodic memories of many instances of behaviors. This is particularly consistent with general reviews of the function of MPFC (BA 10), which suggest that this region is well positioned to support the integration of multiple, internally generated inputs (e.g., Christoff, Ream, Geddes, & Gabrieli, 2003; Dumontheil, Burgess, & Blakemore, 2008), as would be necessary to make higher-order generalizations about one's own abilities and attributes from past experiences. Furthermore, a recent longitudinal study of brain structure in 375 typically developing individuals found that MPFC, MPPC, DMPFC, and TPJ all follow cubic developmental trajectories of cortical thickness: increases in childhood followed by decreases in adolescence and eventual stability in young adulthood (Shaw et al., 2008). Peaks in grey matter density for these regions appear between the ages of 9 and 13 years (on average by 11 years of age), suggesting that after this period there may be a shift in the trajectory of functions associated with these brain regions, which includes self development. In high-competence domains, the brain seems to engage more strongly in working and episodic memory processing via enhanced recruitment of DLPFC and MPPC during the course of making self-evaluations, as well as attain a more affective, motivational orientation via activation of the amygdala.

Beginning in early adolescence, then, we hypothesize that individuals begin to habitually incorporate others' perspectives on the self during

the process of making self-evaluations, as indicated by the involvement of TPJ in particular. On the one hand this may be seen as a change driven by external social factors, such as the growing importance of the peer group. We propose that it may also be driven by biological factors, such as the functional connectivity between MPFC, MPPC, and TPJ observed to increase throughout adolescence (Fair et al., 2008). Additionally during this time, when an evaluative source is perceived to be highly relevant in a domain (such as whether a peer thinks you are popular or not), the brain may tag this information as especially self-relevant, weighting its contribution towards that domain-specific self-concept.

Finally, by adulthood, the vast majority of general evaluative self-knowledge is more likely to be stored and retrieved (from lateral temporal cortex and temporal poles, sites maintaining general and personal or emotional semantic information) than generated on each occasion (see Lieberman et al., 2004; Pfeifer et al., 2007). For particular domains with which we identify strongly or in which we have vast amounts of experience, self-evaluations will be relatively more automatic and intuitive, and involve a different neural system that may include the amygdala and nucleus accumbens, among other regions. These structures facilitate speedy access to self-knowledge and are affiliated with affect and motivation, presumably supporting emotional learning and behavior patterns associated with that domain. Interestingly, because self-development continues throughout the lifespan, one may be able to observe the same neurodevelopmental trajectory in any new domain (for example, when an adult picks up a new hobby, changes careers, or becomes a parent).

FUTURE DIRECTIONS AND CONCLUSION

Throughout this chapter we have attempted to point out promising future directions for this subfield. These have included comparing the neural correlates of general self-knowledge retrieval with accessing information about other social targets besides Harry Potter; exploring the relationship between development of the default network and the functioning of the neural systems supporting evaluative self-knowledge, domain-specific self-concepts, and reflected self-appraisals; studying the neural systems engaged when children or adolescents make self-evaluations in domains for which they possess persistently negative self-concepts; and examining in greater detail how and when younger children and older adolescents recruit networks for social perspective-taking in service of self-perception, compared to early adolescents and adults. One particularly

important avenue of research to pursue would be longitudinal investigations of the neural systems involved in general evaluative self-knowledge retrieval, domain-specific self-concepts, and reflected self-appraisals. For example, using such a strategy would allow us to potentially observe self-schemas emerge and the associated shift in the neural systems supporting self-knowledge in that domain from explicit, integrative, and evidentiary bases in MPFC and MPPC to automatic, affective and motivational bases in the amygdala and nucleus accumbens.

Another critical extension of research in this field would be to examine the functioning of these neural systems in children and adolescents with autism spectrum disorders (ASD), as compared to typically developing individuals. Research on autism has tended to emphasize dysfunctions in social perception, to the relative neglect of disordered self-perception. Recently, a study assessing various components of self-referential processing in adults with ASD demonstrated that memory for both the self and a similar, close other (best friend) was relatively impaired in adults with ASD, but not memory for information processed with reference to a dissimilar, nonclose other (Harry Potter) or to nonsocial features of the stimuli (Lombardo, Barnes, Wheelwright, & Baron-Cohen, 2007). Furthermore, there was a bidirectional interaction between abilities to think about the self and others. More advanced mentalizing skills led to better recall for self-relevant information, while self-focused attention and private self-consciousness was associated with enhanced mentalizing abilities. The authors concluded that being more self-focused was beneficial for individuals with ASD as it may support metacognition, self-reflection, and mentalizing—but that future research using neuroimaging techniques was needed to explore the degree of impairment in self-understanding experienced by these individuals, its relationship to the manner in which they think about close or distant others, and how these patterns develop.

In the past several years, two fMRI studies have found an abnormally hypoactive default network in adults with ASD (for a discussion see Iacoboni, 2006), including failures to deactivate MPFC during a cognitively demanding task (Kennedy, Redcay, & Courchesne, 2006), as well as weakened functional connectivity between anterior (MPFC) and posterior (MPPC) components of the network (Cherkassky, Kana, Keller, & Just, 2006; Just, Cherkassky, Keller, Kana, & Minshew, 2007). Most important, a very recent neuroimaging study of adults with ASD demonstrated that they did not engage cortical midline structures during self-knowledge retrieval (Moran, Qureshi, Singh, & Gabrieli, 2007). These three studies suggest that patterns of neural activity in these

regions during self-referential processing should be studied in childhood and adolescence, as individuals with ASD are building a foundation of self-knowledge to support their future behavior and social interactions. A further, critical step in understanding atypical patterns of self-development in ASD will be not only to study the neural systems supporting self-concepts in a global fashion, but also those supporting the specific process of ascertaining others' perspectives on the self. This kind of social cognitive task—which combines social perspective-taking and self-reflection—includes components that are likely to pose special challenges for individuals with ASD, which may both amplify difficulties in interpersonal relationships and negatively impact their self development.

In conclusion, our understanding of the neural systems supporting self development (including general evaluative self-knowledge, domain-specific self-concepts, and reflected self-appraisals) is still in its early stages. Yet this field of developmental social cognitive neuroscience holds much promise, both applied and theoretical. We may be able to learn more about the systems that support typical self-development through the lens of children and adolescents with autism, who grapple with difficulties in self-perception, as well as create treatments that cultivate their abilities to amass evaluative self-knowledge and take other people's perspectives about them. The mechanisms that enable domain-specific self-concepts to motivate and guide behavior may be revealed, and this information may be used to design interventions to improve negative or affirm positive self-evaluations. A new perspective on the age-old debate about the self-centeredness of adolescents, and their susceptibility to external social influences, may be obtained. At the most philosophical level, a developmental social cognitive neuroscience approach to the self provides a window onto the biological foundations for the development, maintenance, and expression of our beliefs in the essential attributes and abilities that make us unique from any other individual in the world.

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