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The neural signature of self-concept development in adolescence: The role of domain and valence distinctions

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A B S T R A C T

Neuroimaging studies in adults showed that cortical midline regions including medial prefrontal cortex (mPFC) and posterior parietal cortex (PPC) are important in self-evaluations. The goals of this study were to investigate the contribution of these regions to self-evaluations in late childhood, adolescence, and early adulthood, and to examine whether these differed per domain (academic, physical and prosocial) and valence (positive versus negative). Also, we tested whether this activation changes across adolescence. For this purpose, participants between ages 11–21-years (N = 150) evaluated themselves on trait sentences in an fMRI session. Behaviorally, adolescents rated their academic traits less positively than children and young adults. The neural analyses showed that evaluating self-traits versus a control condition was associated with increased activity in mPFC (domain-general effect), and positive traits were associated with increased activity in ventral mPFC (valence effect). Self-related mPFC activation increased linearly with age, but only for evaluating physical traits. Furthermore, an adolescent-specific decrease in striatum activation for positive self traits was found. Finally, we found domain-specific neural activity for evaluating traits in physical (dorsolateral PFC, dorsal mPFC) and academic (PPC) domains. Together, these results highlight the importance of domain distinctions when studying self-concept development in late childhood, adolescence, and early adulthood.

1. Introduction

Adolescence is a life period during which the self-concept undergoes significant changes. For example, adolescents form increasingly abstract self-descriptions and they develop a more differentiated self-concept that varies across domains and different social contexts (Harter, 2012). It is thought that these changes are triggered by the development of cognitive abilities, by taking on new social roles, and by changes in the environment of adolescents (Brown, 2004; Harter, 2012). Importantly, these developmental changes become increasingly domain-specific, with, for example, more differentiated self-evaluations for social, physical and academic domains (Marsh and Ayotte, 2003). These domain-specific self-evaluations may be dependent on contextual factors such as school environment and social relations (Harter, 2012). Additionally, although the positivity bias (the overestimation of own abilities, and unrealistically positive self-views) is thought to decline from childhood to adolescence (Harter, 2012; Trzesniewski et al., 2003), the exact development of the valence of self-evaluations in adolescence is still debated (Steiger et al., 2014). It has been hypothesized that the development of the valence of self-concept also differs per domain (Cole et al., 2001; Shapka and Keating, 2005).

Concurrent with changes in self-evaluations, adolescents show large functional and structural changes in brain structures that are implicated in self-referential processing such as the medial prefrontal cortex (mPFC) and posterior parietal cortex (PCC) (Mills et al., 2014; Pfeifer and Peake, 2012; Somerville et al., 2013). However, to date neuroimaging studies have not yet examined domain- and valence-specificity of self-evaluations in adolescence. The current study set out to test domain and valence differences in self-evaluation in adolescence using functional neuroimaging methods.

1.1. Self-related brain regions

The role of the mPFC in self-evaluations has been well studied in adults. In these studies, participants evaluated whether, and to what extent, certain traits were descriptive of the self. Elevated activation in the ventral and rostral mPFC has consistently been found for self-evaluations relative to other-evaluations or baseline activation (for a review and meta-analyses, see Amodio and Frith, 2006; Denny et al., 2012; Murray et al., 2012). Interestingly, some studies reported

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stronger ventral mPFC activation for evaluating positive traits than for evaluating negative traits (Moran et al., 2006; van der Cruijsen et al., 2017) and this region has previously been linked to positive valuation processes (Kringelbach and Rolls, 2004; Peters and Büchel, 2010). This suggests that the ventral part of the mPFC is especially involved in affective evaluation of self-traits (D'Argembeau, 2013).

In addition to studies focusing on brain regions for general self-evaluations, several studies reported that a broader network of brain regions is involved when comparing self-evaluations across different domains. Evaluating physical traits has been associated with activation in dorsolateral prefrontal cortex (DLPFC), whereas character evaluations have been associated with posterior cingulate cortex (PCC) activation (Moran et al., 2010; Pfeifer et al., 2013; van der Cruijsen et al., 2017).

Recently, several studies investigated the neural activations underlying self-evaluations in childhood and adolescence. A study focusing on 14-to-16-year-old adolescents revealed stronger ventral mPFC, dorsal mPFC and medial posterior parietal cortex (mPPC) activation for evaluations of self compared to evaluations of others (Romund et al., 2017). Other studies reported increased rostral mPFC activation in children (9–10-years) compared to adults (23–31-years) for self-evaluations relative to evaluations of others (Pfeifer et al., 2009, 2007). However, other studies reported similar cortical midline activation for direct self-evaluations for early adolescents (11–14-years) and adults (22–31-years) (Jankowski et al., 2014), and showed that ventral mPFC activation for self-evaluations increased with age and pubertal development in the social but not the academic domain from age 10–13 years (Pfeifer et al., 2013). Similarly, a prior study that found rostral ACC activation during memory encoding for traits of self versus mother, showed that this activation increased from age 7–13 years (Ray et al., 2009). A similar study revealed that activation in this region for self versus a distant other increased across adolescence from age 13–19 (Dégeilh et al., 2015).

Together these studies suggest that mid to late childhood/early adolescence (7–13 years) may be an important period for the development of brain regions underlying self-evaluations and provide initial evidence that these changes may be domain-specific. That is, the development of self-related brain activation might differ for evaluating the self in different domains. However, prior studies included adolescents in narrow age ranges and varying age groups. Consequently, these studies mostly compared specific age groups (children and/or adolescents) with adults. A developmental pattern of self-related brain activation across childhood, adolescence, and early adulthood has not yet been tested. Moreover, it remains to be determined whether adolescents also show neural activations in distinct regions for evaluations in different domains, similar to what has previously been found in adults (Moran et al., 2010; van der Cruijsen et al., 2017).

1.2. Current study

In the current study, we aimed to test domain- and valence-specificity of self-concept development in adolescence, by including a large sample (N = 150) of participants across a broad age range from (11–21-years). For this purpose, participants evaluated themselves on descriptions of positive and negative traits in three domains (academic, physical, prosocial). Our specific aims were 1) to investigate whether ventral/rostral mPFC was more active for self-evaluations compared to a baseline condition in adolescents (Amodio and Frith, 2006; Denny et al., 2012; Murray et al., 2012; Pfeifer et al., 2013, 2007), 2) to unravel domain-specific neural activation with a focus on DLPFC for physical self-evaluations, and PCC for character (academic and prosocial) self evaluations (Moran et al., 2010; van der Cruijsen et al., 2017), 3) to test whether ventral mPFC is more active for evaluating positive than negative self-traits in adolescence, similar to what has previously been reported in adults (Moran et al., 2006; van der Cruijsen et al., 2017), and 4) to explore whether activation in these brain regions would show age-related changes across adolescence (Dégeilh et al., 2015; Jankowski et al., 2014; Pfeifer et al., 2013, 2009, 2007; Ray et al., 2009).

We tested for linear changes with age (both positive and negative) based on studies that compared children/early adolescents with adults (Jankowski et al., 2014; Pfeifer et al., 2009). Even though no prior studies examined changes in self-evaluations from mid to late adolescence, a prior study that examined self-consciousness showed stronger mPFC activation in mid adolescents compared to children and adults when participants believed they were being observed by others (Somerville et al., 2013). Therefore, we also tested whether the activation in self-related brain regions would show a quadratic change.

2. Method

2.1. Participants

This study was part of a larger study (the Leiden Self-Concept study). Participants were 160 right-handed children, adolescents, and young adults, of whom 10 were excluded due to the following reasons: excessive head movements during the fMRI scans (more than 3 mm across the full run, n = 8), did not complete scan (n = 1), and technical error (n = 1). Consequently, a total of 150 healthy participants (80 female) aged between 11 and 21 years old (mean age = 15.7, *SD* = 2.9) were included in the analyses. Motion correlated negatively with age, indicating that older participants moved less during the scan than younger participants ($r = -0.314, p < 0.001$). We added motion parameters to all the analyses to control for these differences (see below).

All participants reported normal or corrected-to-normal vision, and an absence of neurological or psychiatric impairments. Participants completed two subtests of the WISC-III or WAIS-III (Similarities and Block Design). Estimated IQ scores fell between 80.0 and 137.5 ($M = 110.30$, $SD = 11.06$), and IQ did not correlate with age ($r(148) = 0.007$, $p = 0.934$). Pubertal status was assessed using the Pubertal Development Scale (PDS; Petersen et al., 1988). Pubertal status scores ranged from 5 to 20 in girls (mean = 15.3, *SD* = 3.5), and from 5 to 20 in boys (mean = 14.3, *SD* = 4.2). This corresponds to an average PDS stage of 4.15 (range 1–5) for girls, and 3.57 (range 1–5) for boys.

All participants and both parents of minors signed informed consent before inclusion in the study. The study was approved by the University Medical Ethical Committee. Prior to the scan session, participants were screened for MRI contra-indications and self-reported psychiatric diagnoses or psychotropic medication. All scans were viewed by a radiologist and no clinically relevant findings were observed.

2.2. Task description

All participants completed an fMRI task in which they were presented with short sentences describing either positively or negatively valenced traits in the academic, physical or prosocial domain (Fig. 1, Appendix A). In the self-condition, participants were asked to indicate to what extent the trait sentences applied to them on a scale of 1–4. Participants responded to 60 trait sentences (e.g. 'I am smart', 'I am unattractive') by pressing buttons from 1 ('not at all') to 4 ('completely') with the index to little finger of their right hand. Twenty trait sentences were shown for each domain; ten with a positive valence and ten with a negative valence. In the baseline condition, all response demands were the same, except that in this condition participants were asked to categorize other trait sentences according to four categories: (1) school, (2) social, (3) appearance, or (4) I don't know. Twenty trait sentences were shown in this block; ten with a positive valence and ten with a negative valence. The two conditions appeared in separate runs and the order of conditions was counterbalanced across participants. All stimuli and the average number of words per sentence in each condition can be found in Appendix A. Analyses on the sentence length revealed a