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Neural and behavioural correlates of adolescents changing academic self-concept

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Abstract

Background: Mid-adolescence is an important phase of self-development in various domains including academics as well as for changes in the neural mechanisms underlying the self-concept. Students' academic self-concept (ASC) is affected by educational achievements and social others (such as teachers and peers). To what extent these external influences relate to neural dynamics during adolescents' self- and other-evaluations (i.e. of friends and teachers) which affect ASC over time is currently unclear.

Aims: The current study aimed to address the question of to what extent the developing ASC is influenced by developmental changes in self- and other-evaluations (friends, teachers) and their underlying neural mechanisms as well as academic achievement.

Methods: In this interdisciplinary longitudinal fMRI study, forty-seven 13-year-olds (at T1) were instructed to indicate whether positive and negative trait adjectives described themselves (self-evaluations), their teachers, or peers (other-evaluations) at two time points. We investigated how adolescents' academic self-concept is influenced by changes in their academic achievement and self- and other-evaluations (teachers and peers) 1.5-years later.

Results: Behaviourally, both, academic achievement and positive teacher evaluations were important to prevent the observed decline in ASC during mid-adolescence. Our fMRI results showed that cortical midline structures were linked to self-evaluation, whereas the precuneus and occipital regions were related to friends- and teacher-evaluation.

Julia Rodriguez Buritica and Stella Berboth contributed equally to this work.

Here, ASC was predicted by activity changes in the precuneus during friends-evaluations for students with better academic achievement.
Conclusion: Our findings indicate that academic achievement and positive teacher-evaluations could prevent the decline in ASC observed in mid-adolescents and that the neural correlates of evaluating close others within the precuneus present an important link to ASC. The current study highlights the importance of educational neuroscience studies to understand the changing ASC during adolescence.

KEYWORDS
academic achievement, academic self, medial prefrontal cortex, precuneus, self-concept

INTRODUCTION

Mid-adolescence is an important phase for self-development in various domains including school (Harter, 2012). Students' own perception of academic abilities and performance (school or academic self-concept, short ASC; Dickhäuser et al., 2002; Schoene et al., 2012) decreases over time (Shapka & Keating, 2005; van der Cruijsen et al., 2018) and is influenced by various factors such as academic achievement and social others, peers and teachers (Bakadorova & Raufelder, 2015, 2016, 2020). That is, students' academic achievement promotes their ASC and vice versa, cross-sectionally and longitudinally, emphasizing the importance of school self-concept as a possible target for promoting academic achievement (Bakadorova & Raufelder, 2020; Hansen & Henderson, 2019; Marsh et al., 2018; Marsh & Craven, 2006; Marsh & Martin, 2011). Next to that, social others, such as peers and teachers, differently affect ASC (Bakadorova & Raufelder, 2014, 2015, 2017; Raufelder et al., 2015). Here, particularly friends, a subgroup of those peers, positively influence self-concept development (Bukowski et al., 2018; Steinberg & Morris, 2001). Along with peers, teachers play an important role within the school context and are among the five most significant predictors of academic success (Hattie, 2008). Positive teacher-student relationships and socio-motivational support from teachers are related to higher ASC, cross-sectional as well as longitudinal (Bakadorova & Raufelder, 2014, 2016; Raufelder et al., 2015). To what extent these behavioural influences relate to neural dynamics during adolescents' self- and other-evaluations (i.e., for friends and teachers) thereby affecting ASC over time is currently unclear.

Developmental cognitive neuroscience studies support behavioural findings by showing that mid-adolescence is an important phase for changes in the neural mechanisms underlying the self-concept (Cosme et al., 2022; Pfeifer & Berkman, 2018; Pfeifer & Peake, 2012; Sebastian et al., 2008). Here, adolescents' self- and other-evaluations are linked to a broad network including the ventromedial prefrontal cortex (vmPFC) and anterior cingulate cortex (ACC), the dorsomedial prefrontal cortex (dmPFC), the posterior cingulate cortex (PCC), the precuneus as well as the temporal parietal junction (TPJ) (Braams & Crone, 2017; Cosme et al., 2022; van Buuren et al., 2022; van der Cruijsen et al., 2018) similarly to findings in adults (Denny et al., 2012; Murray et al., 2012). Particularly, when comparing self- to other-evaluations, the vmPFC is linked to self-evaluations, whereas the PCC/precuneus are associated with other-evaluations (Braams & Crone, 2017; Cosme et al., 2022; Golde et al., 2019; Pfeifer et al., 2013; Romund et al., 2017; van Buuren et al., 2022; van der Aar et al., 2019; van der Cruijsen et al., 2018). With respect to the ASC, adolescents' self-evaluations in the vmPFC (Golde et al., 2019), precuneus, and temporal lobe (van der Aar et al., 2019) are positively linked to

ASC, whereas teacher-related (but not friend-related) processing in the vmPFC is negatively linked to ASC (Golde et al., 2019). These findings suggest that evaluation of self and others differently affects the ASC. To what extent self- and other-evaluations affect ASC over time is currently unclear. Longitudinal evidences with respect to the developing self-network are mixed (Braams & Crone, 2017; Cosme et al., 2022; Pfeifer et al., 2013; van Buuren et al., 2020). Here, the self-network seems to be related to pubertal development (Pfeifer et al., 2013) showing an inverted U-shaped change across adolescents with activities peaks during mid-adolescence for regions including the vmPFC (Pfeifer et al., 2013) and dmPFC (van Buuren et al., 2022).

The current study builds on these findings and addresses the question to what extent the developing ASC is influenced by developmental changes in self- and other-evaluations (friends, teachers) and their underlying neural mechanisms and academic achievement. To do so, we used an event-related longitudinal fMRI design to examine developmental differences during self-, friends-, and teachers-evaluations during mid-adolescence (i.e., 14–16 years; Barrett, 1996) as an important phase for self-development (Harter, 2012). In this task, participants decided whether different trait words (i.e., positive, negative, neutral) described themselves or others. Additionally, we assessed their ASC (Dickhäuser et al., 2002) and their academic achievement.

Given previous findings in adolescents, we expect that changes in self- and other-evaluations and underlying neural activity as well as academic achievement relate to changes in ASC over 1.5 years: Behaviourally, ASC should decrease over time (Shapka & Keating, 2005; van der Cruijsen et al., 2018) and changes in academic achievement should promote changes in ASC. On a neural level, we predict that self-evaluations are particularly associated with activity within the ACC/vmPFC as compared to other-evaluations that should relate more to activity within the PCC/precuneus. Finally, neural correlates of self- and other-evaluations should be linked to changes in ASC.

MATERIALS AND METHODS

Participants

Eighty-five on average 13-year-old adolescents were recruited from secondary schools for a longitudinal fMRI study. Due to limited availability of the fMRI scanner, only 47 adolescents were randomly selected to take in the fMRI experiment at timepoint 1 (T1; data already published, Golde et al., 2019; Romund et al., 2017) and 39 out of these completed the fMRI-study 1.5 years later (timepoint 2; T2). In order to be included in the analysis, these 39 fMRI participants must not show more than 3 mm translation and 3° head rotation during the fMRI paradigm in line with previous studies (Golde et al., 2019; Romund et al., 2017). None of the participants had to be excluded based on excessive head movement. Thus, the final sample consisted of 39 adolescents (T1: mean age (SD) = 13.19 (0.46); 20 females; T2: mean age (SD) = 14.74 (0.44)). All participants were screened for MRI contra-indications and revealed normal or corrected to normal vision, did not have adverse health conditions or psychological disorders, or used medications influencing the central nervous system. 38 out of 39 participants were right-handed. As data analyses without the one left-handed participant revealed equivalent results, we report results including all 39 participants. All participants and at least one legal guardian per informant gave written, informed consent. The study was approved by the ethics committee of the German Psychological Society and carried out in accordance to the Declaration of Helsinki. Participants participated in one experimental session for each timepoint assessing behavioural measures (Section 2.2.) and their individual pubertal development using the Puberty Developmental Scale (short PSD; Petersen et al., 1988), a self-report about sexual characteristics including growth, body hair, changes in skin, changes in voice and facial hair (boys) and breast development (girls) (T1: mean PSD (SD) = 2.74 (0.64); T2: mean PSD (SD) = 3.09 (0.38)).

Questionnaires

Academic self-concept

The Academic self-concept (ASC) was measured at both timepoints (T1 and T2) using the subscale "absolute school self-concept" of the German Scale for Assessment of School Self-Concept (Dickhäuser et al., 2002; Schoene et al., 2012) in line with previous research (Bakadorova & Raufelder, 2020; Golde et al., 2019). This scale consists of five items each designed to measure students' perception of their academic abilities without considering comparative measures (i.e., time, peers or criterion) (T1: $\alpha = .80$; T2: $\alpha = .82$ internal consistency for the present sample). The questionnaire was rated on a five-point Likert scale, ranging from 1 (I totally disagree) to 5 (I totally agree).

Academic achievement

Academic achievement was measured at both timepoints (T1 and T2) by students' self-reported grades on their most recent report cards in the following subjects: German, mathematics, English and biology. As the German system of grades ranges from 1 ("very good") to 6 ("insufficient"), a higher score means lower scholastic achievement. For the purpose of clarity, all grades were reverse-coded in the current study.

Self- and other-referencing task

We used a self-referential paradigm (see Figure 1; controlled by Presentation® software; see also Golde et al., 2019; Romund et al., 2017). Participants were asked to decide whether or not a certain trait-adjective (e.g., "naive," "smart") described themselves or others, all their current friends and their current teachers.[1] The paradigm included additionally a control condition, where participants had to judge whether or not the adjective had exactly two syllables. In each condition, trials followed the same general structure: The experimental condition (i.e., the reference person "you," "friends" and "teachers," or the control condition "syllables") was presented above a central fixation cross and one trait-adjective was presented below the fixation cross (2.5 s). Participants answered whether they thought the adjective accurately described the respective reference person by pressing the left or right button of a MR-compatible response pad. Trials were separated by an exponentially varying jittered fixation cross (1.5–9.5 s). Each trait-adjective out of 30 was presented in all five different judgement conditions resulting in 150 trials, that were randomized within the experiment. Before performing the task in the MRI, participants practised the task on average 35 ($SD = 10$) trials for timepoint 1 and 33 ($SD = 16$) trials for timepoint 2 until participants felt thoroughly comfortable with all parts of it.

Adjectives were drawn from the Berlin Affective Word List (Võ et al., 2006) and were counterbalanced based on emotional valence and arousal of the words. Adjectives with medium arousal (between 2 and 4 on a 5-point scale) were chosen, out of which 10 words with a positive valence, 10 with a neutral and 10 with a negative valence were then selected in a second step (see Golde et al., 2019 for more details and a list of all trait adjectives used in the experiment). In order to investigate how evaluations of self and other affected ASC, we computed the proportion of chosen positive over

[1]Note that in line with our research question, we focused just on the other referential conditions "friends" and "teachers". However, the task contained also the other-referential condition "politicians", that is not shown here in the main manuscript. Analyses including "politician" did not reveal any additional effects for the behavioural analyses (p's > .06). FMRI analyses including the "politician" condition revealed similar results, including no significant main effect of time or interaction effect.

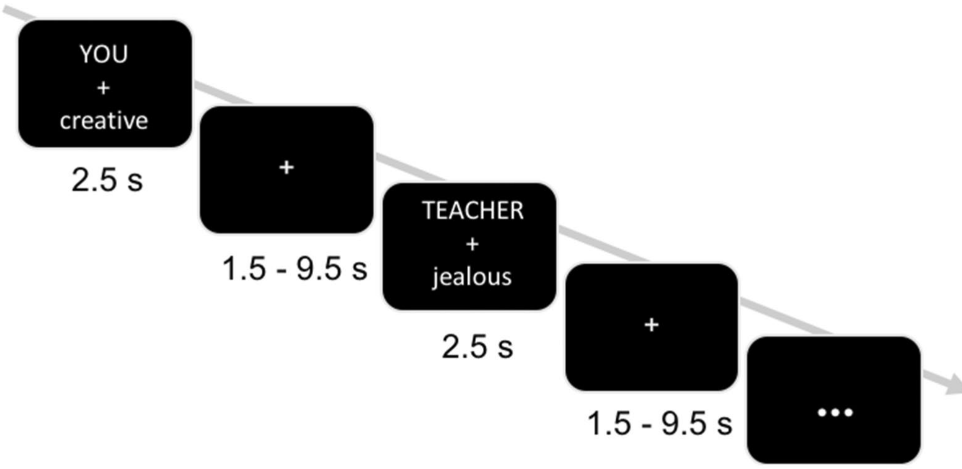

FIGURE 1 Task design. Each trial consisted of the presentation of the experimental condition (i.e., the reference person "you," "friends," "teachers" or the control condition "syllables") above a central fixation cross and one trait-adjective presented below the fixation cross (2.5 s). Trials were separated by an exponentially varying jittered fixation cross (1.5–9.5 s).

negative trait-adjectives (trait-positivity scores). Here, higher scores indicated more positive evaluations of the respective person.

FMRI data acquisition

Whole-brain functional and anatomical images were acquired using a SIEMENS 3 Tesla Magnetom Trio scanner and a 12-channel head coil. A T1-weighted 3D MPRAGE dataset was acquired for each participant (192 sagittal sections, $1 \times 1 \times 1\,mm^3$; 256×256 data acquisition matrix, TR = 1.9 s; TE = 2.52 ms, field of view = 256×256; flip angle = 9°). Functional images were acquired using a T2*-weighted gradient echo planar imaging (EPI) sequence (TR = 2 s; TE = 30 ms; 33 slices; voxel size = $3 \times 3 \times 3\,mm^3$; 0.8 mm slice gap; field of view = $192 \times 192\,mm^3$; flip angle = 78°). For each experimental run, 450 whole-brain volumes were recorded.

Data analyses

Analyses of behavioural data

First, we assessed whether longitudinal changes in the academic self-concept were predicted by longitudinal changes in behavioural variables using mixed-effects generalized linear model (as implemented in the lme4 package in R; Bates et al., 2014). Here, ASC was modelled by using the within-subject predictor time (T1, T2), reference condition of interest (*self*, *friends*, *teachers*), trait-positivity (proportion of selected positive traits) and mean grades, controlling for puberty scores.

Mixed effects model formula:

$$\text{ASC} \sim \text{time}^{*}\ \text{reference condition}^{*}\ \text{trait positivity}^{*}\ \text{grades} + \text{Puberty} + (1|\,\text{id})$$

The categorical predictors were contrast-coded (i.e., time [0,1]), condition was treated as factor, and all continuous predictors were mean-centred. Regression weights (beta values), z-values and corresponding p-values are reported in the Table S1.

FMRI data analyses

Functional MRI data were analysed using SPM12 (Statistical Parametric Mapping, Welcome Centre for Human Neuroimaging, London, UK). Preprocessing included slice-time correction, realignment and coregistration to the respective structural image of the participant. The MPRAGE images were then segmented, and EPIs were transformed into the stereotactic normalized standard space (Montreal Neurological Institute, MNI) by using the segmentation transformation matrix. Finally, data was smoothed with an isotropic Gaussian kernel (6 mm full-width at half-maximum).

Effects on the first level were estimated with an event-related general linear model (GLM) convolving each trial with the haemodynamic response function. Modelled events of interest for the self- and other-referencing task were the task conditions (i.e., type of judgement: *self*, *friends*, *teachers*, or *syllables*). Six movement parameters were included in the model as nuisance regressors. Based on the resulting parameters, differential contrast images were created for each timepoint in which the control condition (*syllables*) was subtracted from every referencing condition (*self*, *friends*, *teachers*).

The resulting single-subject contrast images were submitted to the second-level group analysis. A random-effects GLM was computed using a flexible factorial design. The model consisted of two within-subject factors: task condition (*self*, *friends*, *teachers*) and time (*T1*, *T2*). Contrasts were computed to test for the main effects of time and condition and the interaction effect. The whole-brain results were tested for significance using an initial cluster-defining threshold $p < .001$, corrected for multiple comparisons with family wise error rate (FWE) at $p < .05$. Coordinates of the results are reported in MNI space.

Finally, we assessed whether longitudinal changes in the academic self-concept were predicted by longitudinal changes in behavioural measures and brain activation in regions involved in self- and other-evaluations using mixed-effects generalized linear model (as implemented in the lme4 package in R). For this, we defined two regions of interest (ROIs), ACC/vmPFC and the precuneus. The ROIs were functionally determined by using 10-mm radius spheres centred on the peak coordinates of activation within the ACC/vmPFC (−3, 41, 2) based on the [*self* > *friends* + *teachers*] contrast and within the PCC/precuneus (15, −49, 5) based on the [*friends* + *teachers* > *self*] contrast. For each subject and each timepoint, the average contrast estimates were extracted for the *self* condition within the ACC/vmPFC and for the *teachers* and *friends* condition within the precuneus.

Next, extending our behavioural analyses, ASC was modelled by using the within-subject predictor time (T1, T2), reference conditions (*self*, *friends*, *teachers*), trait-positivity (proportion of selected positive traits) and mean grades as well as activity during self- as well as teachers- and friends-evaluations within the respective ROIs, controlling for puberty scores. Regression weights (beta values), *z*-values and corresponding p-values are reported in the Tables S5 and S6.

RESULTS

Behavioural results

To test the effects of time, reference condition, grades and trait-positivity scores on ASC, we used a mixed-effects general linear model (controlling for puberty; see methods). The results of this analysis (see Table S1) showed that ASC decreased over time ($\beta = -0.31$, $t = -2.86$, $p = .005$) and increased with higher grades ($\beta = 0.18$, $t = 2.28$, $p = .024$). Interestingly, we found a time x grade x trait-positivity interaction for the teacher-condition ($\beta = 0.69$, $t = 3.42$, $p < .001$). Separate regressions per time revealed a grade x teacher-trait-positivity interaction only for T2 ($\beta = 0.4$, $t = 3.6$, $p < .001$), but not for T1 ($p = .9$). Here, better academic achievement and more positive students' evaluations of their teachers predicted higher ASC (see Figure 2).

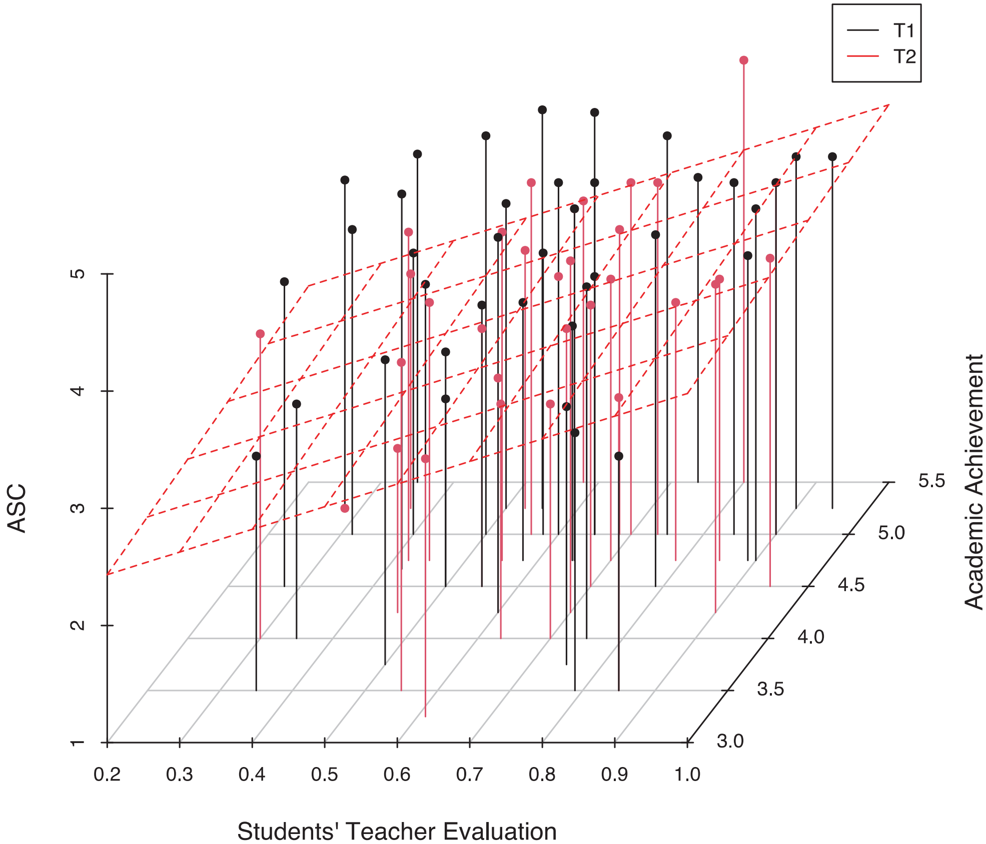

FIGURE 2 ASC per Students' Teacher Evaluation & Academic Achievement for T1 (displayed in black) and T2 (displayed in red). More positive ASC was associated with higher students' evaluation of teachers and academic achievement for T2, but not for T1. Dots reflect individual data points.

fMRI results

Whole-brain analyses

First, we investigated activity changes due to the effects of condition and time and the interaction of condition and time. Testing for the main effect of time and the interaction effect of time and condition revealed no significant results. A main effect of condition was observed within a widespread network of cortical midline structures as well as frontal, temporal and parietal regions (Figure 3a, Table S2).

To further investigate differences in activity between the respective conditions, post hoc paired sample *t*-tests were conducted. For the [*self*>*friends*] contrast, enhanced activity in a widespread network of regions was shown. We found increased activity in cortical midline structures (anterior cingulate cortex, ACC; superior medial frontal cortex/ventromedial prefrontal cortex, vmPFC; middle cingulate cortex, MCC; precuneus), as well as frontal (bilateral inferior frontal gyrus, IFG), temporal (bilateral middle temporal gyrus; MTG; left superior temporal gyrus, STG) and parietal (left supramarginal gyrus) regions and bilateral insula. The reverse contrast [*friends*>*self*] showed increased activity in the lingual gyrus and the precuneus as well as the superior temporal gyrus and the Rolandic operculum (Figure 3b, Table S3).

Testing the effect of self- vs. teachers-evaluations [*self*>*teachers*] revealed enhanced activation in cortical midline structures (ACC; superior medial frontal cortex/vmPFC; MCC; precuneus), frontal (bilateral IFG; right MFG), temporal (bilateral MTG; left STG) and parietal (left supramarginal

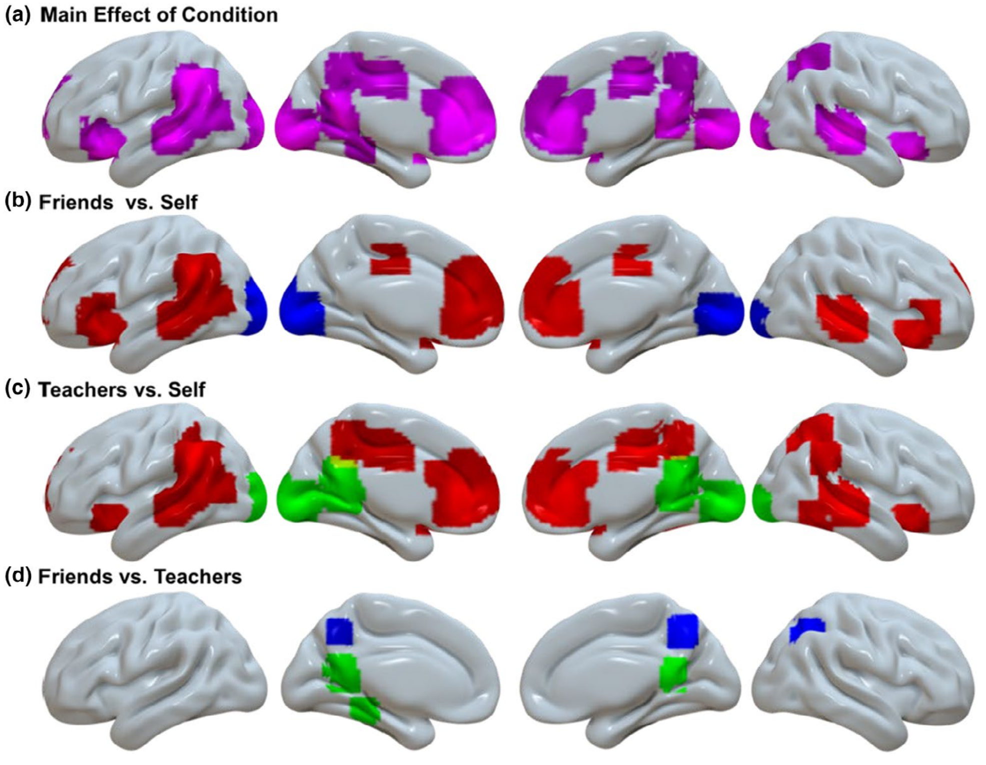

FIGURE 3 (a) Brain activation for the main effect of condition across both timepoints. (b) Brain activation during self- vs. friends-evaluations. [*self* > *friends*] is indicated by red colour, [*friends* > *self*] is indicated by blue colour. (c) Brain activation during self- vs. teachers-evaluations. [*self* > *teachers*] is indicated by red colour, [*teachers* > *self*] is indicated by green colour. (d) Brain activation during teachers- vs. friends-evaluations. [*teachers* > *friends*] is indicated by green colour, [*friends* > *teachers*] is indicated by blue colour. Results are shown at a cluster-defining threshold of $p < .001$ and a $p < .05$ FWE-corrected cluster threshold.

gyrus; right angular gyrus) regions as well as the left insula. For the reverse contrast [*teachers* > *self*], increased activation was found in the calcarine fissure as well as the precuneus and lingual gyrus (Figure 3c, Table S3). Finally, testing for the effect of teacher- vs. friend-evaluations, we found increased activation in the dorsal part of the precuneus, bilateral inferior parietal gyrus, right angular gyrus and postcentral gyrus for the [*friends* > *teachers*] contrast. The reverse contrast [*teachers* > *friends*] demonstrated enhanced activity in the ventral part of the precuneus and left fusiform gyrus (Figure 3d, Table S3). To summarize, testing for the effects of self- vs. friends- and teachers-evaluations resulted in a similar widespread network of regions, including cortical midline structures such as the ACC/vmPFC, temporal and frontal regions, that was consistent with previous studies in adolescents testing for the effect of self vs. other-evaluations (e.g., Cosme et al., 2022; Murray et al., 2012; Pfeifer et al., 2013; van Buuren et al., 2022; van der Cruijsen et al., 2018). In line with previous studies testing for the reverse effect (e.g., Cosme et al., 2022; van Buuren et al., 2020), we observed increased activity within posterior midline regions and the lingual gyrus, when comparing the other-evaluations conditions to the self-evaluations condition, with additionally increased activity in left temporal regions during the friends condition. We therefore used the contrast of self- vs. other- (friends and teachers) evaluations [*self* > *teachers* + *friends*] and the reverse contrast [*teachers* + *friends* > *self*] for defining the ACC/vmPFC and the precuneus as ROIs. Details of the results are reported in the Table S4.

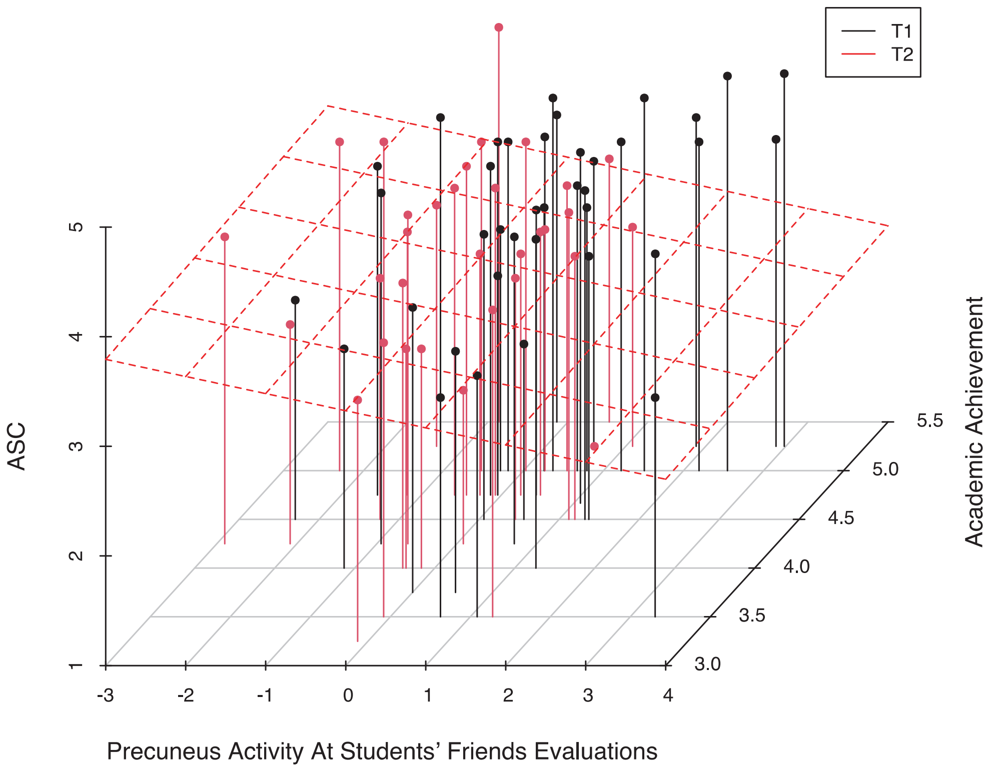

FIGURE 4 ASC per Precuneus Activity at Students' Friend Evaluations & Academic Achievement for T1 (displayed in black) and T2 (displayed in red). More positive ASC was associated with reduced precuneus activity and better academic achievement for T2, but not for T1. Dots reflect individual data points.

Brain-behaviour-relations

Finally, we examined to what extent whole-brain measures specifically for self-, friends- and teachers-evaluations additionally helped to explain longitudinal changes in ASC. Here, we extracted parameter estimates from whole-brain clusters of interest that responded specifically to the self-evaluation condition (i.e., ACC/vmPFC) and the other-evaluation condition (i.e., precuneus) and added them separately to the baseline model (resulting in 2 models; see Tables S5 and S6 respectively). Extending our behavioural results, we found a time x precuneus activity × grade × other-evaluation condition interaction ($\beta = 0.77$, $t = 2.01$, $p = .047$; survived FDR correction for multiple comparisons; see Figure 4) specifying the time x precuneus activity × grade interaction ($\beta = -0.74$, $t = -2.38$, $p = .017$; survived FDR-correction for multiple comparisons). Separate regressions per other-evaluation condition revealed a time × precuneus activity × grade interaction only for the friend ($\beta = -0.36$, $t = -2.37$, $p = .021$), but not for the teacher condition ($p = .3$).

Separate regressions per time revealed a precuneus activity × grade interaction only for T2 ($\beta = -0.32$, $t = -2.23$, $p = .034$), but not for T1 ($p = .3$). Here, better academic achievement and reduced precuneus activity during students' friends-evaluations predicted higher ASC (see Figure 4). Separate analyses for median-splitted grades (Median = 4.75) showed that for higher grades reduced precuneus activity predicted ASC ($\beta = -0.46$, $t = -2.1$, $p = .05$), but not for lower grades ($p = .88$). We did not observe any significant interactions with respect to the ACC/vmPFC (p's > .3).

DISCUSSION

In this study, we examined the neural and behavioural correlates of the changing academic self in mid-adolescents (within 1.5 years). Overall, we found that ASC decreased over time and increased with better academic achievement. Adolescents' changing ASC was predicted by better students' evaluations of teachers and better academic achievement (see Figure 2). Whole brain fMRI analyses showed enhanced activity in a widespread network of regions, including cortical midline-brain structures like the ACC/vmPFC during self-evaluations (*self > friends* and *self > teachers*; see Figure 3) and parietal regions such as the precuneus (see Figure 3) during other-evaluations (*friends > self* and *teachers > self*). Finally, separate brain-behavioural analyses revealed that reduced precuneus activity during friend-referential processing at T2 was related to ASC (see Figure 4). We structured the discussion along the lines of the main findings.

First, our findings support longitudinal findings in adolescents showing a decrease of ASC over time (Bakadorova et al., 2020; Shapka & Keating, 2005; van der Cruijsen et al., 2018). However, better academic achievement and better students' teacher-evaluations predicted higher ASC at T2, but not at T1. This finding is in line with previous results showing that students' academic achievement promotes their ASC and vice versa (Marsh & Craven, 2006; Marsh & Martin, 2011) and longitudinal evidences showing that both are positively linked to each other over time (Bakadorova & Raufelder, 2020; Hansen & Henderson, 2019; Marsh et al., 2018). Also, more positive students' evaluations of teachers lead to an increase of the ASC. This supports previous findings in adolescents suggesting that a more positive teacher evaluation prevents a decline in school motivation (Bakadorova & Raufelder, 2014). Our results add to that and indicate that both, academic achievement and positive teacher evaluations, are important to prevent a decline in ASC.

Our fMRI results support previous findings regarding self-and other-evaluations in adolescence: In line with previous studies, self-evaluations (*self > friends* and *self > teachers*; see Figure 3) were linked to a broad network including cortical midline-structures such as the ACC/vmPFC (Cosme et al., 2022; Debbané et al., 2017; Murray et al., 2012; Pfeifer et al., 2013). These structures showed a stronger involvement during self- as compared to other-evaluations of trait adjectives that suggest a higher importance of processing of self-related information. Here, particularly the ACC/vmPFC has been assumed to be important for the evaluation and monitoring during self-evaluations (Braams & Crone, 2017; Murray et al., 2012; Northoff et al., 2011). Additionally, we observed the involvement of temporo-parietal regions that have been reported to be important for self-related imagery and evaluations as well as first-person perspective taking, such as the anterior precuneus (Cavanna & Trimble, 2006; van der Meer et al., 2010; Vogeley & Fink, 2003), and are involved in personal information processing, such as the temporal gyrus (Martinelli et al., 2013). However, these regions are also linked in other referential processing and with that represent a shared neural network (Braams & Crone, 2017; Cosme et al., 2022; De Brigard et al., 2015; Debbané et al., 2017; Qin & Northoff, 2011; van Buuren et al., 2022). During other-evaluations (*friends > self* and *teachers > self*; see Figure 3), we observed pronounced activities in the calcarine fissure as well as the posterior precuneus and lingual gyrus. Here, particularly the precuneus has been linked to the social network, perspective taking and episodic memory retrieval (Cavanna & Trimble, 2006; D'Argembeau et al., 2007; Dosch et al., 2010; Ruby & Decety, 2004; Wagner et al., 2005). Activities in the precuneus during other-evaluations have been assumed to reflect the retrieval of other-related experiences (D'Argembeau et al., 2007). Additionally, we observed activities in the visual cortex (such as the lingual gyrus) in line with previous research reporting the involvement of the visual cortex during other referential judgements (Newsome et al., 2012). This might reflect a visual imagery component important for the retrieval of autobiographical memory (D'Argembeau et al., 2007; Greenberg & Rubin, 2003) with respect to others.

When comparing the teachers- vs. friends-evaluations, enhanced activity was observed in the ventral area of the precuneus for the [*teachers > friends*] contrast. The reverse contrast yielded increased activity in the dorsal part of the precuneus. We thus replicated the findings of Romund et al. (2017), that emphasized a subdivision of the medial posterior parietal cortex/Precuneus, in our longitudinal dataset. The authors suggested that retrieving information from the episodic memory to judge teachers may be more difficult than retrieving content for friends, resulting in enhanced activity within this part of the PCC, that has been linked to episodic memory retrieval. Interestingly, we could not replicate the finding of Romund et al. (2017), showing increased activity within the ACC/vmPFC when comparing the friends to the teachers' condition. A possible explanation might be, that in our study, whole-brain analyses were performed, whereas Romund et al. (2017) used a region-of-interest approach when comparing both conditions.

Both, neural activity underlying self- and other-evaluations, did not significantly change over time. Only a few studies to date investigated longitudinal changes in brain activation associated with self- and other-evaluations in adolescence (Braams & Crone, 2017; Cosme et al., 2022; Pfeifer et al., 2013; van Buuren et al., 2022). These studies showed an inverted U-shaped function in neural activity during self- and other-evaluations from mid-adolescents to young adulthood (Cosme et al., 2022; van Buuren et al., 2022). The peak and stabilization in activity during mid-adolescents has been assumed to reflect the stabilizing self-concept (van Buuren et al., 2022). However, results of these studies are mixed and the picture of developmental changes in neural activity during self-evaluations remains unclear, as studies report changes in only a few, differential regions, including the vmPFC (Pfeifer et al., 2013; van der Cruijsen et al., 2018), dmPFC and TPJ (Pfeifer et al., 2009; van Buuren et al., 2022), whereas another study in young adolescents failed to observe any effect of age (Barendse et al., 2020). One possible explanation, why we did not observe an effect of time in our study, is the age range within our longitudinal design (i.e., 13–15 years). A recent longitudinal study (van Buuren et al., 2022) showed that activity significantly increased within regions of interest, including dmPFC and TPJ, from 13 years to 14 years, but did not show any time effect when comparing neural activity to the third timepoint (15 years). The only other study implementing a longitudinal design showed increased neural activity within the vmPFC during self-evaluations for an age span of 10–13 years (Pfeifer et al., 2013). Thus, our study adds to previous, mixed findings on developmental changes within the neural network underlying self- and other-evaluations, as we did not find a significant effect within the here studied range of age. Further longitudinal studies are needed to clarify developmental changes in the neural activity underlying self-evaluations.

When inspecting self- and other-evaluations conditions separately, ASC was particularly predicted by brain-behaviour relations in the friends-evaluation condition. Here, our results showed that precuneus activity during the evaluation of friends interacting with higher academic achievement was positively linked to better ASC during mid-adolescents. This result adds previous developmental findings showing that the precuneus plays a crucial role for the academic self-concept (van der Aar et al., 2019) and extends these by highlighting its role during other-evaluations affecting ASC. In line with previous findings in adolescents highlighting the importance of peers for the self-concept (Jansen et al., 2022; Molloy et al., 2011; Trautwein et al., 2009), this effect was particularly pronounced for friends-evaluations. Separate comparisons per grades revealed that reduced activity in the precuneus at T2 predicted higher ASC for students with better academic achievement. This result suggests that specially in adolescents with high school performance the neural activity within precuneus during the evaluation of friends is associated with better academic self-evaluations. As activation during other-evaluations in the precuneus has been linked to autobiographic memory retrieval (Cavanna & Trimble, 2006), reduced activity within the precuneus might be associated with less difficulties to retrieve content from the episodic memory during friends' evaluation. Whether this effect might be explained by more relatedness and similarities with friends or perceived competition with peers in students striving for high grades has to be investigated in future studies. Here, it would be interesting to compare these effects also between favourite and less favourite friends (and teachers) as the current study only assessed their evaluations about all their friends (and teachers), irrespectively of how much they like them. Additionally, comparing evaluations of single friends (and teachers) instead of a group (as it was done here) with self-evaluations will help comparing the neural correlates of these different evaluation processes better with each other. Future studies should further investigate the relationship between neural correlates of social evaluation processes and academic achievement. In contrast to our hypothesis, we did not find any association of neural activity during self-evaluations within the vmPFC and ASC. Although a previous publication of the data of T1 found a positive association for vmPFC during self-evaluations and ASC in a manifest path analysis (Golde et al., 2019), it has to be noted that this study assessed a different research question, namely the link of perceived loneliness and functional correlations during self-and other-evaluations in relation to ASC – next to methodological differences. Next, future studies should additionally include larger sample sizes to also assess bidirectional links between variables influencing ASC using Cross-Lagged Panel models.

To summarize, our findings suggest that academic achievement and positive teacher evaluations could prevent the decline in ASC observed in mid-adolescents and that the neural correlates of the evaluation of close others within the precuneus present an important link to ASC. The current findings show that behavioural and neurobiological factors influence the development of ASC. With that, our study highlights the importance of educational neuroscience studies in order to understand the development of ASC.

AUTHOR CONTRIBUTIONS

D.R. designed the research. Anne Beck, Eva Flemming, Tobias Gleich, Sabrina Golde, Robert Lorenz and Lydia Romund performed the experiments and J.M.R.B. and S.B. analysed data. J.M.R.B., S.B., F.H. and D.R. interpreted the findings and wrote the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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