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Do Belonging and Social Exclusion at School Affect Structural Brain Development During Adolescence?

Diana Raufelder*,
University of Greifswald

Nicola Neumann*, and Martin Domin
University Medicine Greifswald

Robert C. Lorenz
Max-Planck Institute for Human Development

Tobias Gleich, Sabrina Golde, and Lydia Romund
Charité—University Medicine

Anne Beck
Charité—University Medicine and HMU Health and Medical University Potsdam

Frances Hoferichter
University of Greifswald

Students' sense of belonging presents an essential resource for academic and health outcomes, whereas social exclusion at school negatively impacts students' well-being and academic performance. Aiming to understand how feelings of school-related belonging and exclusion shape the *structural* brain development, this study applied longitudinal questionnaire-based data and MRI data from 71 adolescent students (37 females, M_{age} at t1 = 15.0; t2 = 16.1 years). All were white participants from Germany. Voxel-based morphometry revealed only an association of social exclusion (and not of belonging) and gray matter volume in the left anterior insula: From t1 to t2, there was less gray matter decrease, the more social exclusion students perceived. School-related social exclusion and disturbed neurodevelopment are thus significantly associated.

Being accepted by and affiliated with others is a deeply rooted inner human desire, known as the need to belong (Baumeister & Leary, 1995). As children spend an enormous amount of time in school, relationships with their classmates and teachers are essential to satisfy this inner need. The sense of belonging experienced by students (e.g., being accepted by others) presents a crucial resource for academic and health outcomes (Gillen-O'Neel & Fuligni, 2013; Walton & Cohen, 2011; Wang & Holcombe, 2010), whereas social exclusion (e.g., being rejected by others) at school negatively influences student well-being and academic performance (Arslan, 2016; Buckley, Winkel, & Leary, 2004; Raabe, 2019; Walton & Cohen, 2011). As peerinteractions and friendships become increasingly important and complex during adolescence (e.g., Gillen-O'Neel & Fuligni, 2013; Osterman, 2000; Pittman & Richmond, 2007), the benefit of social belonging and the distress of social exclusion is believed to be particularly high in this period (see Gunther Moor, 2011; Somerville, 2013).

However, adolescence is not only marked by increased complex social relationships (Bukowski, Simard, Dubois, & Lopez, 2011) and a more complex sense of the self and its qualities (Harter, 1999), but also by major structural and functional developmental brain changes (see Blakemore, 2008, 2010). The question, therefore, arises as to what

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Correspondence concerning this article should be addressed to Diana Raufelder, Institute of Educational Science, University Greifswald, Ernst-Lohmeyer-Platz 3, 17487 Greifswald, Germany. Electronic mail may be sent to diana.raufelder@uni-greifswald.de.

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extent adolescents' feelings of social belonging and exclusion are associated with their brain development. Several *functional* brain development studies have shown that belonging and social exclusion are associated with brain activity in areas of the so-called social brain (Cacioppo et al., 2013; Dalgleish et al., 2017; Gunther Moor et al., 2012; Kawamoto, Ura, & Nittono, 2015; Masten et al., 2009; Wang, Braun, & Enck, 2017), which is associated with the navigation of complex social environments facilitating interaction and cooperation with others (Chen, Martínez, & Cheng, 2018). To our knowledge, only a few longitudinal studies have investigated the relationship between social stressors (e.g., peer victimization) and *structural* brain development in adolescents (du Plessis, Smeekens, Cillessen, Whittle, & Güroğlu, 2019; Quinlan et al., 2020; Tyborowska et al., 2018), although structural MRI data and analyses can provide important insights for exploring how social factors can impact brain development.

In sum, most of the existing studies investigating belonging and social exclusion are based on functional MRI (fMRI) and not structural MRI data, whereas only one of these studies (du Plessis et al., 2019) included school-related variables, although the daily life of adolescents is mainly determined by their social relationships at school. The present interdisciplinary study was conceptualized to contribute to this research body by focusing on (a) healthy adolescents, (b) structural brain development through adolescence, and (c) both belonging and social exclusion at school. As there are only a few longitudinal studies on social stressors and structural brain development based on data from small samples (du Plessis et al., 2019; Quinlan et al., 2020; Tyborowska et al., 2018), this study follows a rather exploratory than confirmatory approach.

Belonging and Social Exclusion at School

Belonging at school can be defined as a student's sense of being accepted, valued, and integrated at school, including through encouragement by their peers and teachers (Baumeister & Leary, 1995; Faircloth & Hamm, 2005; Osterman, 2000). Studies have revealed that school belonging supports student health and well-being (see Gillen-O'Neel & Fuligni, 2013), positive emotions (Fong Lam, Chen, Zhang, & Liang, 2015), and academic performance (Bryan et al., 2011; Ma, 2003; Osterman, 2000; Skinner, Furrer, Marchand, & Kindermann, 2008; Walton & Cohen, 2011; Wang & Holcombe, 2010). The need-to-belong theory (Baumeister, 2012) states that social belonging contributes to the emotional, cognitive, and behavioral development of individuals. As such, social belonging may also affect developmental changes in adolescent brains.

In contrast to belonging, social exclusion at school is characterized by feelings of being a loner and disliking school entirely (Ramm et al., 2006), and is often associated with repeated perceptions of rejection and ostracism (Baumeister & DeWall, 2005). It is well-known that social exclusion can generally have detrimental effects on the health and well-being of an individual (Arslan, 2018; Buckley et al., 2004; Eisenberger, Lieberman, & Williams, 2003; Walton & Cohen, 2011) and is associated with poor school performance (Arslan, 2016; Ladd, & Kochenderfer-Ladd, 2016; Raabe, 2019). There is a high prevalence of peer stressors associated with exclusion (e.g., bullying and victimization) at school with a peak particularly in mid-adolescence (Quinlan et al., 2020; Wang, Iannotti, & Nansel, 2009). Mid-adolescence is further interesting as:

> whole-brain gray matter volumes decrease drastically until children reach approximately 15 or 16 years with a subsequent slower decrease (e.g., Brain Development Cooperative Group, 2012), indicating a great synaptic reorganization (e.g., Blakemore, 2008), presumably due to synaptic pruning processes (e.g., Huttenlocher, 1994; Gabriel et al., 2021, p. 544).

The Neural Correlates of Belonging and Social Exclusion in Adolescence

Several of the fMRI studies to date investigated adolescents' neural responses to belonging and social exclusion (Dalgleish et al., 2017; Fritz et al., 2020; Gunther Moor, 2011; Gunther Moor et al., 2012; Masten et al., 2009; Sebastian et al., 2011; Vijayakumar, Cheng, & Pfeifer, 2017). All the studies identified activation due to social exclusion in the regions of the anterior insula (AI), the anterior cingulate cortex (ACC), and the prefrontal cortex (PFC). More precisely, the dorsal ACC and the AI were similarly activated during the social rejection and acceptance feedback (Dalgleish et al., 2017). Both brain regions seem to be particularly relevant for the detection and appraisal of adverse social situations (Fritz et al., 2020; Kawamoto et al., 2015). While the insula is involved in cognitive control, emotion, motivation, and pain, and as such functions as a neural "alarm system" (Eisenberger et al., 2003; see Fritz et al., 2020), the dorsal ACC is particularly related to the evaluation and specification of cognitive control and reward-based learning and decision making (Bush et al., 2002; Fritz et al., 2020; Shenhav, Cohen, & Botvinick, 2016). Social exclusion also elicited a response in the bilateral medial PFC (mPFC) and in the ventrolateral PFC (vlPFC; Gunther Moor et al., 2012; Sebastian et al., 2011), which are related to processing social evaluation, negative affective processing, and affect regulation, respectively (see Sebastian et al., 2011). The activity in the AI and in the subgenual ACC was found to be related to greater exclusion-related distress in adolescents, whereas the right ventrolateral prefrontal activity was negatively related to self-reported distress (Masten et al., 2009). However, none of these studies focused on the impact of belonging and exclusion on the social brain in relation to the school context.

While fMRI is able to investigate associations between neural activity and social belonging and exclusion, structural MRI can assess long-term consequences of environmental factors on gray and white matter changes within the brain. Adolescence is a sensitive period characterized by extensive structural changes with widespread and regionally variable decreases in gray matter volume (GMV; see Tamnes et al., 2017). More particularly, the brain regions responsible for the higher order social-cognitive and behavioral regulatory functions, as well as the self-referential and theory of mind processes (e.g., parts of the PFC) have been shown to exhibit decreasing linear and quadratic trajectories (Vijayakumar et al., 2016). Environmental experiences influence the different regions of the brain in dependence of the age the experience occurs and the developmental status of the respective brain structure. The GMV of the PFC, for example, has been shown to be particularly sensitive during mid-adolescence (Teicher, Samson, Anderson, & Ohashi, 2016).

With regard to social stressors, a previous MRI study indicated that generalized anxiety in the context of peer victimization was associated with a steeper decrease in left putamen volume (Quinlan et al., 2020). A study investigating the links between peer victimization and cortisol assessed at age 9 and structural brain development of the ventrolateral PFC (vlPFC) assessed at age 14 found a smaller right vlPFC surface area in boys with a low daily cortisol output (du Plessis et al., 2019). Another longitudinal study could show that adolescents who were disliked by their peers showed smaller gray matter decreases in cortical regions (anterior cingulate, parahippocampus, and PFC), and an increased GMV in the hippocampus (Tyborowska et al., 2018). The authors interpreted their findings to indicate that an unfavorable social environment during adolescence disturbs brain maturation, such as cerebral developmental trajectories were delayed or disrupted by current social stress (Tyborowska et al., 2018).

The Present Study and Hypotheses

In order to provide deeper insights into the GMV development associated with belonging and exclusion at school, the present longitudinal, interdisciplinary study was conceptualized using MRI, and questionnaire data at two time points each. Given that social exclusion (e.g., bullying) at school is at its peak in mid-adolescence (Quinlan et al., 2020; Wang et al., 2009) and GMV changes quickly (Vijayakumar et al., 2016), we chose this developmental period to investigate the following hypotheses:

The school belonging and social exclusion at school reported by 15-year-old adolescents are associated with changes in GMV in the following year. Adjusting for GMV changes in a whole-brain approach using voxel-based morphometry, we expect the brain regions associated with social acceptance and exclusion to be affected. These include the ACC, the amygdala, hippocampus, AI, mPFC and medial orbitofrontal cortex, parts of the lateral PFC, and ventral striatum. Since adverse social factors may interfere with brain development (Tyborowska et al., 2018), the experience of social exclusion is assumed to be related to smaller decreases in GMV (i.e., disturbed brain maturation), particularly in the ACC and AI (Dalgleish et al., 2017).

Method

Participants

The study forms part of a longitudinal study on socioemotional learning factors (SELF study), which focuses on the development of adolescents by following an interdisciplinary and mixed-method design in a large sample of 1,088 ($M_{\text{age}} = 13.70$, $SD = 0.53$, 53.9% girls) secondary school students in the federal state of Brandenburg (Germany). All the adolescents were assessed at the beginning of the eighth grade and the end of the ninth grade ($M_{\text{age}} = 14.86$, $SD = 0.57$, 55% girls; dropout rate of

22.33%). Of all the students whose parents and themselves gave consent to participate in the MRI study, 88 students were randomly selected. Equal distribution was ensured with regard to the gender of the students as well as the type of school (vocational track and academic track). Due to the small proportions of people with migrant background in Brandenburg (2.6%) our subsample was not refined by the migrant background of students. Additionally, due to German privacy law restrictions that prohibit asking students for information about their parents, socioeconomic status, parents' educational level, and parents' migrant background could not be determined. This recruited subsample from the SELF study ($n = 88$) underwent MRI in the middle of the ninth grade in 2013 (t1, $M_{\text{age}} = 15.03$; $SD = 0.51$; 50% girls) and in the middle of the tenth grade in 2014 (t2, $M_{\text{age}} = 16.10$, $SD = 0.95$, 52% girls). For the current investigation, we included all the participants who had taken part in both MRI scanning sessions ($n = 75$). One participant's segmentation failed, leaving 74 data sets for analysis. Of those, 71 participants had completed the questionnaire items regarding school belonging and social exclusion (see the following section). This final sample consisted of 37 females (52%) and 34 males, with a mean age of 14.9 years ($SD = 5.98$) at t1 and 16.0 years ($SD = 6.08$) at t2. The mean duration between the scanning sessions was 13.01 months ($SD = 1.94$). Mean handedness was 72.6 ($SD = 36.2$, range −100 to 100; 3 left-handed).

Procedure

The SELF study was authorized by the Brandenburg Department of Education, Youth, and Sport. The schools, parents, and students provided written informed consent to participate in both the questionnaire study and the MRI study. The MRI study was additionally approved by the ethics committee of the German Psychological Association. Before conducting the study, the students were assured that their responses would be treated confidentially and that their participation was entirely voluntary. In order to introduce the aims of the study and to answer potential questions from the students, three research assistants were present in the classrooms during the study. All participants were screened for the following exclusion criteria: (a) adverse health conditions, neurological or psychological disorders (currently or history of), (b) use of medications that influence central nervous system function, (c) nonremovable ferromagnetic material, (d) learning disabilities. Handedness was measured using the Edinburgh Handedness Inventory (Oldfield, 1971).

Questionnaire Measures

School Belonging

The students' sense of belonging at school was also assessed using the PISA 2003 questionnaire (Ramm et al., 2006), originally developed by Willms (2003). The three items (e.g., "My school is a place . . . at which I feel I belong" or ". . .where I easily find friends") were ranged from 1 (*strongly disagree*) to 4 (*strongly agree*) on a 4-point Likert scale. The scale showed good reliability at both measurement points (T1: $\alpha = .78$, T2: $\alpha = .78$; see Table 1).

Table 1
Detailed Description of All Items Used to Assess School Belonging and Social Exclusion

Measure	Items	Range 1 = "strongly disagree", 4 = "strongly agree"
School belonging	My school is a place . . .	
	at which I feel I belong	1–4
	where I easily find friends	1–4
	where I seem to be popular	1–4
Social exclusion	My school is a place . . .	
	where I often feel uncomfortable and out of place	1–4
	where I feel as an outsider	1–4
	where I feel lonely	1–4
	to which I do not want to go	1–4
	where I am often alone	1–4

Note. Adapted from Ramm et al. (2006), originally developed by Willms (2003).

Social Exclusion at School

Social exclusion at school was assessed using the PISA 2003 questionnaire (Ramm et al., 2006). Five items on a 4-point Likert scale were used (e.g., "My school is a place . . . where I feel lonely" or ". . .where I feel as an outsider"), which ranged from 1 (*strongly disagree*) to 4 (*strongly agree*). The scale indicated good reliability at both measurement points (T1: α = .75, T2: α = .72; see Table 1).

Pubertal Status

Puberty was measured via an adapted version of the Pubertal Development Scale (Petersen, Crockett, Richards, & Boxer, 1988) and included questions such as "Did you notice hair growths, for example under your arm pit or pubic hair?", while answers ranged from 1 = *no, I do not grow any hair yet* to 4 = *I think the growths of my pubic hair is already over*.

Neuroimaging Methods

Imaging Data Acquisition

The structural images were obtained using a T1-weighted three-dimensional magnetization prepared rapid gradient echo sequence, with an isotropic spatial resolution of 1 mm^3:192 slices, repetition time = 1,900 ms, echo time = 2.52 ms, flip angle = 9°, field of view = 256 × 256, matrix size = 256 × 256.

Voxel-Based Morphometry

Structural brain image data analyses were performed using the longitudinal pipeline of the Computational Anatomy Toolbox (CAT12; http://www.neuro.uni-jena.de/cat/index.html#VBM) running on MATLAB (The MathWorks, Natick, MA). The default settings of the CAT12 toolbox were used. This involved segmentation into GMV, white matter, and cerebrospinal fluid; affine registration to the stereotactic Montreal Neurological Institute (MNI) space; high-dimensional DARTEL normalization; and nonlinear modulation using the Jacobian determinants derived from the normalization process. The GMV difference images were obtained by subtracting the images at t1 from the images at t2. Finally, the images were smoothed using an 8 mm full width at half maximum Gaussian kernel to compensate for potential inaccuracies during the normalization step and to render the intensities more normal. The image quality rating (IQR; ranging from 0.5 to 10.5 with values around 1 and 2 describing (very) good image quality (grades A and B) and values around 5 (grade E) and higher (grade F) indicating problematic images) and the total intracranial volume (TIV) were calculated automatically by the CAT12 toolbox segmentation pipeline and were later used as nuisance variables. Image quality in this study was good (t1: *M* = 1.95, *SD* = 0.07, range = 1.89−2.30; t2: *M* = 1.94, *SD* = 0.05, range = 1.88−2.18), so that all images could be included in the analysis.

Statistical Analyses

Multiple-regression analyses were performed to test the linear relationships between school belonging and social exclusion and the GMV differences between t1 and t2. Because we aimed to predict later structural brain development from the preceding values for school belonging and social exclusion, we used the t1 values as independent variables. We entered age, sex, and pubertal status as covariates to consider their correlation with the GMV. The IQR and the TIV were included as nuisance variables during the statistical analysis to remove the related variance. For thresholding, we applied $p < .05$, family-wise error (*I*) corrected for multiple comparisons for the whole brain. Additionally, we performed a region of interest (ROI) analysis with $p < .05$ (corrected for multiple comparisons within ROIs (see below), using a composite anatomical mask including the brain areas involved in social exclusion according to the meta-analyses of Cacioppo et al. (2013; bilateral AI, the left ACC, and the left inferior orbitofrontal cortex) and Vijayakumar et al. (2017; developmental sample: right ventral striatum, and left ventrolateral PFC (BA 47) extending into the lateral orbitofrontal cortex) in addition to the hippocampus derived from the structural brain development study of Tyborowska et al. (2018; see below). In accordance with our hypotheses, we investigated the aforementioned brain regions bilaterally and, in an explorative approach, also included the bilateral amygdala. We used the identical mask for investigating school belonging/social acceptance, since similar neural structures underlie both types of social evaluation (Dalgleish et al., 2017). The spatial assignment of the GMV differences above the statistical threshold was conducted with the Statistical Parametric Mapping (SPM) Anatomy Toolbox, Version 2.2c (Eickhoff et al., 2005).

The "social acceptance and exclusion" composite mask included the following brain areas:

ACC: The ACC mask was created using the bilateral Brodmann areas 25, s24, s32, and 33 (Palomero-Gallagher et al., 2015) of the Anatomy Toolbox.

Amygdala: An anatomical ROI was created that included the left and right amygdala nuclei AStr, CM, LB, and SF (Amunts et al., 2005) of the Anatomy toolbox.

Hippocampus: We used the mask provided in Anatomy including CA1–CA3, dentate gyrus, Subiculum, HATA region (Amunts et al., 2005).

AI: The AI mask was provided by Neuromorphometrics (Inc.)

Mesial frontal pole: The mask consisted of bilateral areas Fp2 of the Anatomy Toolbox (Bludau et al., 2014).

Orbitofrontal cortex: The mask consisted of bilateral areas Fo 1–3 of the Anatomy Toolbox (Henssen et al., 2016).

Brodmann area 47: The bilateral mask of BA 47 was taken from the "Automated anatomical labeling atlas" (AAL; Tzourio-Mazoyer et al., 2002).

Ventral striatum: The mask was created using the basal ganglia mask provided by AAL (Tzourio-Mazoyer et al., 2002) including the area with z-values of ≤ 0.

Results

Behavioral Measures

The mean school belonging index was 2.87 (SD = 0.56, 1–4) at t1 and 2.85 (SD = 0.50, 1.33–4) at t2. School belonging did not change significantly between the assessments ($t_{70} = 0.26$, $p = .80$). Mean social exclusion was 1.83 (SD = 0.57, 1–3.6) at t1 and 1.87 (SD = 0.53, 1–3.2) at t2. Social exclusion did not change significantly between the assessments ($t_{70} = -0.61$, $p = .54$).

Regression Analyses of Voxel-Based Morphometry Data

The regression analysis with school belonging at t1 as independent and GMV difference between t1 and t2 as dependent variables revealed no significant influence of school belonging, neither in the whole-brain family-wise error (FWE)-corrected, nor in the small volume corrected contrast. The regression analysis with social exclusion at t1 as independent and GMV difference between t1 and t2 as dependent variable did not show any significant effect in the whole-brain FWE-corrected analysis. There was a significant effect in the left AI, when using small volume correction with our composite mask (MNI: −39, 2, −8, $k = 299$ voxels, $t = 4.42$, $p_{\text{FWE}} = .038$; Figure 1). The cluster included parts of the left posterior insula (MNI: −41, −2, −17) and extended to the left temporal pole (MNI: −47, 9, −30; Figure 1) when applying a more liberal statistical threshold ($p = .001$, uncorrected). The left ACC (MNI: −6, 32, 11, $k = 7$ voxels $t = 3.67$, $p_{\text{FWE}} = .041$) and right AI (MNI: 41, 6, −12, $k = 10$ voxels, $t = 3.48$, $p_{\text{FWE}} = .034$) were significant when small volume correction with the ACC and right AI masks alone was applied.

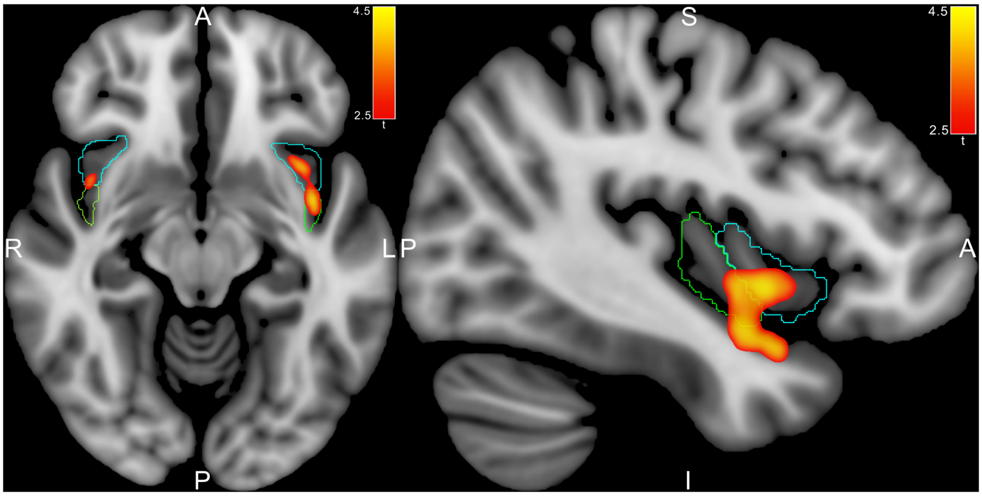

Figure 1. Social exclusion at t1 was associated with the gray matter volume change in the left anterior insula (AI) between t1 and t2 (red hot colored areas at sagittal slice plane $x = -40$, and axial slice plane $z = -11$). The significant cluster encompassed parts of the left anterior (blue outline) and posterior (green outline) insula and extended to the left anterior temporal pole. For visualization purposes, a voxel-threshold of $p < .001$ (uncorrected) was used. The right AI did not reach the statistical threshold corrected for multiple testing.

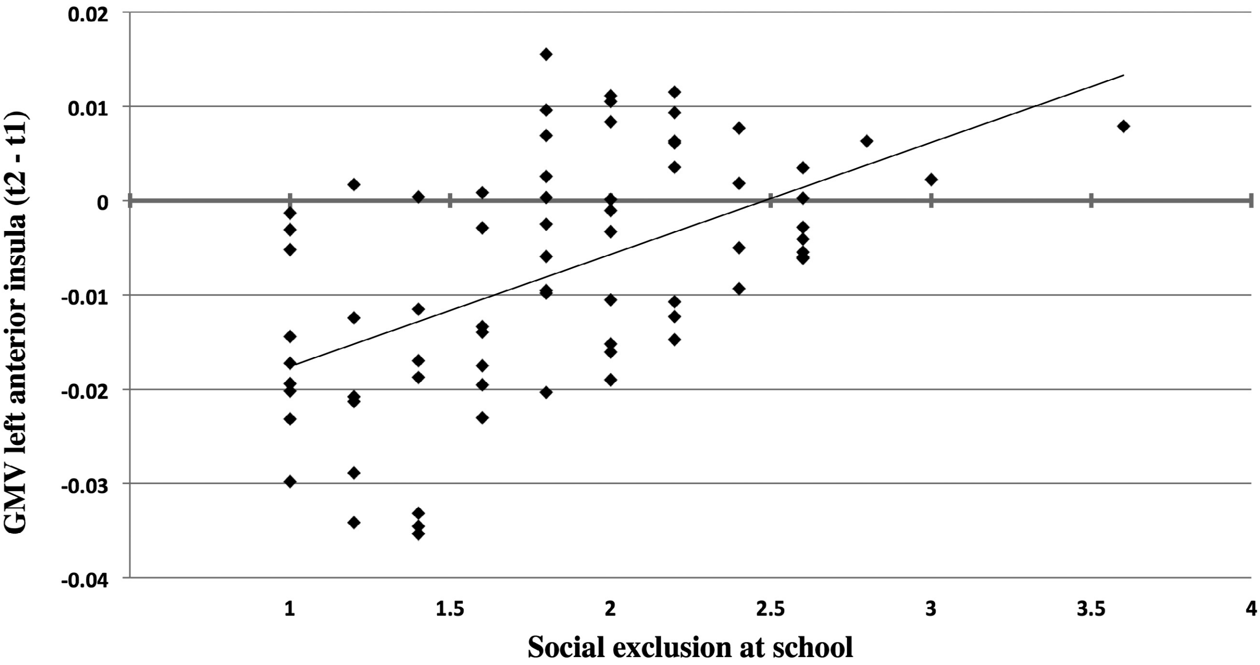

Figure 2. Gray matter volume (GMV) change in the left anterior insula between t1 and t2 in dependence of social exclusion at t1. A smaller value of social exclusion goes along with a GMV decrease (negative values t2–t1).

To further explore the relationship between social exclusion and the development of left AI GMV between t1 and t2, the significant cluster of the SPM statistics was extracted for each subject indicating their respective local GMV change. As depicted in Figure 2, a smaller value for social exclusion at t1 predicted a larger GMV decrease in the left AI between t1 and t2. A decrease of GMV over time is in accordance with the normative development in adolescence (Tamnes et al., 2017).

Discussion

While there are several fMRI studies on belonging and social exclusion and the brain activity of adolescents (Dalgleish et al., 2017; Fritz et al., 2020; Gunther Moor, 2011; Gunther Moor et al., 2012; Masten et al., 2009; Sebastian et al., 2011), there is only one study to date focusing on the structural development of the vlPFC of adolescents that considers social influences in the school context (du Plessis et al., 2019). The present longitudinal, interdisciplinary study was conceptualized using MRI and questionnaire data, and aimed to provide deeper insights into the neuroanatomical basis of the individual variation experienced in relation to school belonging and exclusion.

In contrast to the hypotheses, we did not find an association of school belonging to structural changes of the AI, which contradicts findings that have indicated that the AI is also involved in positive social interactions (Dalgleish et al., 2017; Spagna et al., 2018). This might be due to the fact that the measure we used assesses more generally students' sense of social belonging at school. More specific social indicators (e.g., friendship, romantic relationship) might have stronger effects on the structural brain development as shown in previous studies (Foulkes & Blakemore, 2018; Kawamichi et al., 2016).

In line with the hypotheses, social exclusion of 15-year-old adolescents was associated with changes in GMV in the following year. In particular, whole-brain voxel-based morphometry revealed that the more social exclusion students perceived at T1, the lesser their left AI GMV decreased over time. This finding is in line with the assumption of Tyborowska et al. (2018) that adverse social factors may interfere with brain development, which is characterized by a widespread GMV decrease in adolescence (Tamnes et al., 2017). Furthermore, this finding expands the results of fMRI studies with adolescents, which have shown that the AI is activated by feedback cues of exclusion (Dalgleish et al., 2017; Fritz et al., 2020; Gunther Moor, 2011;

Gunther Moor et al., 2012; Masten et al., 2009; Sebastian et al., 2011). More specifically, Masten et al. (2009) demonstrated that insular activity was positively related to adolescents' self-reported distress. This might indicate that there are associations between structural and functional changes in the AI of the developing brain, which should be investigated in future studies.

In contrast to other studies investigating the influence of social stressors on brain structure (du Plessis et al., 2019; Quinlan et al., 2020; Tyborowska et al., 2018), there were no further areas associated with social exclusion in this study. These differences may be explained by other measures for social stress (social ill-being at school vs. peer victimization) and a shorter period between longitudinal measurements. Additionally, our sample exhibited rather low social exclusion, so its influence on brain structure may have been limited. Future studies taking into account different social stressors and their nuances at school (e.g., social exclusion, peer victimization, bullying) could certainly provide more detailed insight into differences or similarities with respect to the nature of stressors and their role in the structural brain development of this particular age groups.

To summarize, this study has shown that social exclusion at school affects the structural development of the left AI GMV of students. Teachers and educators should be aware that social exclusion in class has detrimental and long-term effects on a child's development. It may impair the maturation of the social brain in such a way that it hinders a student's interaction and cooperation with others (Chen et al., 2018). As such, this study contributes to the understanding of the maturing brain with respect to social functioning. It provides insight into how the development of the social brain can be supported and, consequently, how social competence can be fostered within schools. Social functioning forms a key aspect of learning and academic performance and, by investigating the maturation processes of the brain in relation to the social context at school, it is possible to identify mechanisms and interventions that will contribute to the success of students (see Blakemore, 2010).

Strength, Limitations, and Future Directions

Certain limitations merit consideration: First, there was an average duration of 13 months between the two MRI sessions, which means that the results only provide insight into a certain developmental phase in adolescence. Future studies with additional measurement points from late childhood, and early to late adolescence are needed in order to extend the present findings. Aside from these limitations, this study provides evidence that the left AI is relevant to social exclusion in school. The study is based on a relatively large sample in comparison to other MRI studies with healthy adolescents and provides longitudinal data. Moreover, its interdisciplinary design makes the study one of the first to link school variables to the neural structure of the developing adolescent brain. Future studies that combine fMRI and MRI data could detect associations between the structural and functional changes in the developing brain.

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