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The role of peers and teachers as motivators on adolescents' neural emotional processing predicting feelings of loneliness, depression and stress: Results of an interdisciplinary study

Lydia Pöhland, Diana Raufelder

Abstract
This interdisciplinary multi-method study was designed to examine the role of peers and teachers as motivators on adolescents' neural processing of emotional stimuli affecting stress, loneliness and depression in a sample of 9th and 10th grade students (N = 84) in secondary schools in Brandenburg, Germany. Combining the data from functional magnetic resonance imaging (fMRI) and data from a quantitative questionnaire study, a structural equation model (SEM) was constructed to test the association between the variables of interest. The results of the SEM revealed that students reporting to perceive their teachers and peers as positive motivators showed stronger amygdala activity when students were shown angry teacher and peer pictures, which in turn predicted subjective measures of stress, loneliness and depression.

Keywords: fMRI, Amygdala, Teachers, Peers, Emotion processing, Stress, Loneliness, Depression

Die Rolle von Peers und Lehrern als Motivatoren in Bezug auf die neuronale Emotionsverarbeitung Jugendlicher als Prädiktoren von Einsamkeit, Depression und Stress: Ergebnisse einer interdisziplinären Studie

Zusammenfassung
Die vorliegende interdisziplinäre multimethodale Studie wurde konzipiert, um die Rolle von Peers und Lehrer/-innen als Motivatoren in Bezug auf die neuronale Verarbeitung von emotionalen Stimuli in der Amygdala und deren Auswirkungen auf Einsamkeit, Depression und Stress in einer Stichprobe von Schüler/-innen der 9. und 10. Klasse (N= 84) in Sekundarschulen in Brandenburg zu untersuchen. Durch die Zusammenführung von experimentellen Daten, die mittels funktioneller Magnetresonanztomographie (fMRT) erhoben wurden, und Daten einer quantitativen Fragebogenstudie wurde ein Strukturgleichungsmodell konzipiert, um die erwarteten Zusammenhänge zwischen den Variablen empirisch zu testen. Die Ergebnisse des Strukturgleichungsmodells zeigen, dass Schüler/-innen, die ihre Lehrer/-innen und Peers als positive Motivatoren wahrnehmen, eine stärkere Aktivierung der Amygdala zeigen, wenn sie wütende Lehrer/-innen- und Peer-Bilder betrachten und verarbeiten. Die Stärke der Aktivierung der Amygdala wiederum fungiert als Prädiktor von Einsamkeit, Depression und Stress.

Schlagworte: fMRT, Amygdala, Lehrer, Schüler, Emotionsverarbeitung, Stress, Einsamkeit, Depression

1 Introduction and theoretical background

Adolescents spend an enormous amount of time at school, where social interactions with peers and teachers dominate their daily life (cf. *Harter* 1996). Considering the increasingly complex nature of social relationships during adolescence (cf. *Bukowski* et al. 2011), both interactions with peers and teachers become essential for students' personal development (cf. *Birch/Ladd* 1996; *Harter* 1996) and their motivation (cf. *Raufelder* et al. 2013; *Wentzel* 2002). An underlying component of these socio-motivational relationships in adolescents' school context are emotions: while positive emotions[1] within students' relationships with teachers and peers positively affect their motivation (cf. *Hamre/Pianta* 2006; *Harter* 1996; *Wentzel* et al. 2010), achievement and well-being in school (cf. *Flanagan/Erath/Bierman* 2008; *Raufelder/Bukowski/Mohr* 2013), negative emotions within relationships with teachers (e.g., through constantly negative feedback from teachers) and peers (e.g., through social exclusion, competition) can lead to a decrease in students' motivation and achievement (cf. *Wentzel* 2002), associated with higher dropout rates (cf. *Bergeron/Chouinard/Janosz* 2011) and poor school performance in general (cf. *Buhs/Herald/Ladd* 2006; *DeRosier/Kupersmidt/Patterson* 1994). Unfortunately, starting with the transition to secondary school, adolescents perceive their teachers as more emotionally distant and consequently less friendly, supportive, warm and caring than teachers in elementary school (cf. *Harter* 1996; *Hawkins/Berndt* 1985). In addition, adolescent students have to deal with increasingly complex emotional peer structures, such as feelings of jealousy, exclusion, peer pressure and competition (cf. *Azmitia/Kamprath/Linnet* 1998; *Harter* 1996). As longitudinal research with different age groups of students has shown, negative emotional states show a peak in prevalence particularly during adolescence (cf. *Compas/Hinden/Gerhardt* 1995; *Petersen* et al. 1993). In comparison to adults, adolescents' emotional responses also tend to be more intense, diverse and subject to extremes (cf. *Arnett* 1999; *Buchanan/Eccles/Becker* 1992). Briefly, from a neurobiological perspective, one possible explanation could be a decreased influence of the frontal cortex, leading to an increased activity in the limbic system (e.g. amygdala) (cf. *Somerville/Fani/McClure-Tone* 2011). For the investigation of neural emotion reactivity it is assumed that emotions are the response to external or internal stimuli that lead to certain behavioral changes accompanied by neurophysiological reactions (cf. *Steinfurth/Wendt/ Hamm* 2013). In this context, the utilization of facial expressions as an external stimulus has become a widely used method in fMRI studies, especially for targeting the amygdala. This approach has also been found to be fruitful in adolescent research: results from a large study indicate that angry and neutral facial expressions are highly salient to adolescents, whereupon the highest activation for facial expression has been found in the amygdala (cf. *Schneider* et al. 2011). The amygdala is one of the core regions involved in emotion processing and response modulation (cf. *Fossati* 2012). In this context, the amygdala is proposed to be involved in the detection of socially relevant events and also personally relevant stimuli (cf. *Sander/Grafman/Zalla* 2003). Studies have shown that salient stimuli lead to an elevated amygdala activity, which is an automated process independent of attention (cf. *Vuilleumir* 2009). Since alterations in emotional experience and behavior are core features of many psychiatric disorders (e.g. major depression, anxiety disorder, personality disorder), also alterations in amygdala activity have been indicated. FMRI studies in major depressive disorder (MDD) for instance reported increased amygdala activation during the anticipation of negative pictures (cf. *Abler* et al. 2007) and in response to negative cues (*Greening* et al. 2013). Also, greater memory sensitivity to negative stimuli has been associated with MDD (cf. *Hamilton/Gotlib* 2008). Particularly during puberty, the risk for depression increases (cf. *Kessler/Avenevoli/Ries Merikangas* 2001). But adolescence is also being described as an important developmental stage with biological, psychological as well as social challenges and therefore an increased vulnerability to mental diseases in general (cf. *Paus/Keshavan/Giedd* 2008). Yet, the development or causes for mental disorders are very complex and there are large individual differences regarding contributing factors: genetic vulnerability (e.g. familial liability), heritable traits (e.g. neuroticism) and biographical/environmental factors (e.g. life events, social status) (cf. *Weir/Zakama/Rao* 2012). Regarding the latter, studies have shown that peer rejection and hence loneliness is an important source of stress, which may contribute to adolescent depression (cf. *Platt/Kadosh/Lau* 2013). But the peer group does not only seem to have an influence on the etiology of psychopathology, it also has an impact on neural responses in general: a study by *Grosbras* et al. (2007) showed that adolescents who reported less resistance to pressure from their peer group had a stronger neural response to angry body movements. Therefore, negative stimuli could be especially relevant for adolescents who are more sensitive to the peer group. Relational distresses as well as a more general perception of stress are of high relevance during adolescence (cf. *Seiffge-Krenke/Aunola/ Nurmi* 2009), where resilience to stressful situations as well as vulnerability processes are mediated by brain functional processes. Given a certain stressor, evaluation processes on the significance of the stimuli (e.g. amygdala) as well as the regulation of physiological and behavioral responses are initiated (cf. *McEwen/Gianaros* 2010).

The question is whether these findings can be transferred to a healthy population of adolescent students and their school context. Based on findings regarding an involvement of the amygdala in the detection of personally relevant stimuli, supposing a stronger amygdala activity in response to salient stimuli (cf. *Sander/Grafman/Zalla* 2003; *Vuilleumir* 2009), we assumed that students who rate their socio-motivational relationships with peers and/or teachers as high, would show stronger amygdala activation in response to angry peer and teacher faces. Also, findings regarding increased amygdala responses to negative stimuli in depression led to the question whether students' activation level of the amygdala – while watching angry peer and teacher faces – could predict feelings of stress, loneliness and depression.

2 Current Study

Based on the above-mentioned empirical findings from educational psychology and neuroscience, the current interdisciplinary study[2] aimed to examine if adolescent students' evaluation of peers and teachers as positive motivators and their related neural processing of negative peer and teacher emotions (anger) predicts subjective ratings of stress, loneliness and depression. In detail, the current study examined the following three hypotheses:

Hypothesis I: Association between socio-motivational relationships, neural emotion processing and stress, loneliness and depression. We hypothesized that there would be a positive association between students' evaluation of peers and teachers as positive motivators, students' processing of angry peer and teacher faces in the amygdala as well as students' feelings of stress, loneliness and depression.

Hypothesis II: Students' evaluation of socio-motivational relationships predicts response levels to negative peer and teacher emotions in the amygdala. We hypothesized that both students' evaluation of peers and teachers as positive motivators would positively predict their neural response to negative peer and teacher emotions (anger) in the amygdala.

Hypothesis III: Students' amygdala response to negative teacher emotions predicts stress, loneliness and depression. In detail, we assumed that students' neural emotion processing of negative peer and teacher emotions (anger) would positively predict stress, loneliness and depression.

3 Method

3.1 Participants

In order to conduct a fMRI study about neural emotion processing by using a so-called faces task, a subsample of 87 adolescents was randomly selected from the participant pool of a larger quantitative study ($N = 830$; $M_{age} = 15.35$; $SD = .49$) from secondary schools in the German federal state Brandenburg. As part of the larger quantitative study, these students additionally completed questionnaires on their evaluation of peers and teachers as motivators, as well as their perceived feelings of stress, loneliness and depression. Only 84 out of the 87 participants have been considered in the analyses, as three had to be excluded: One due to incomplete data, one due to excessive head movements (more than 3 mm translation or 3° rotation) and one due to neuroanatomical abnormalities.

3.2 Procedure

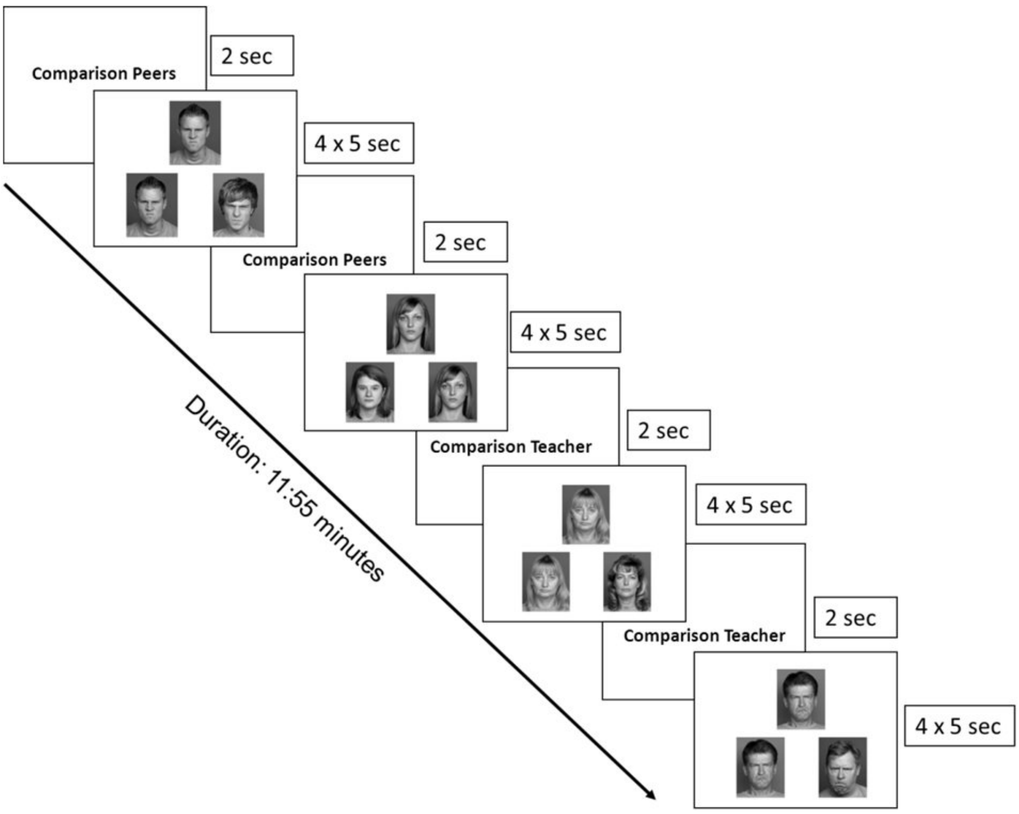
Permission was successfully sought from the Department of Education, Youth and Sports of Brandenburg to conduct this study. Subsequently, parental permission was obtained. Before conducting the study, thorough instructions on the completion of questionnaires and usage of Likert scales, as well as information on voluntary participation including confidentiality and the non-obligation to answer each question had been given. The questionnaire part of the study is based on self-reports, because we were particularly interested in students' views and perceptions of their peers and teachers as motivators and their feeling of stress, loneliness and depression.

In preparation of the experimental neuroimaging part of this study, students were carefully screened for MRI exclusion criteria (e.g. non-removable ferromagnetic material). Both students and one parent (or a person who has care and custody of the child) gave written informed consent. The fMRI study was performed in accordance with the latest version of the Declaration of Helsinki and approved by the ethics committee of the German Psychological Society, Göttingen, Germany.

3.3 Neuroimaging Analyses

Experimental Faces Paradigm. Study participants underwent a modified cue-comparison paradigm, according to *Hariri* et al. (2002), which was programmed using Presentation software (Version 14.9, Neurobehavioral Systems Inc., Albany, CA, USA). In this task, three facial pictures were shown simultaneously: one target face in the upper row and two faces in the lower row. Subjects were instructed to respond as fast as possible via button press which of the faces in the lower row matches the target face. The facial pictures were presented in a blocked-design with blocks of fearful, happy, angry and neutral faces and derived from the FACES database (cf. *Ebner/Riediger/Lindenberger* 2010). Due to the small sample size related to structural equation modeling (SEM), and therefore a limited number of variables in a model, only the results from the angry faces have been used in the current analysis. In order to differentiate between the processing of peer and teacher faces, peer (age 18-22) and teacher faces (age 39-55) for each of the emotional categories were used. Each block started with a short instruction (2 s) with either "comparison peers" or "comparison teacher". The presentation of the blocks was randomized and each block consisted of 4 face comparisons with either young or older faces of the same emotion category. In total, 64 face comparisons of facial expressions were presented. Male and female faces were counterbalanced within each block. Each comparison was presented sequentially for 5 seconds, which resulted in an overall duration of 11.55 minutes (see Figure 1).

Figure 1. Example of the faces task. Alternating blocks of angry peer and neutral peer faces as well as angry and neutral teacher faces were presented



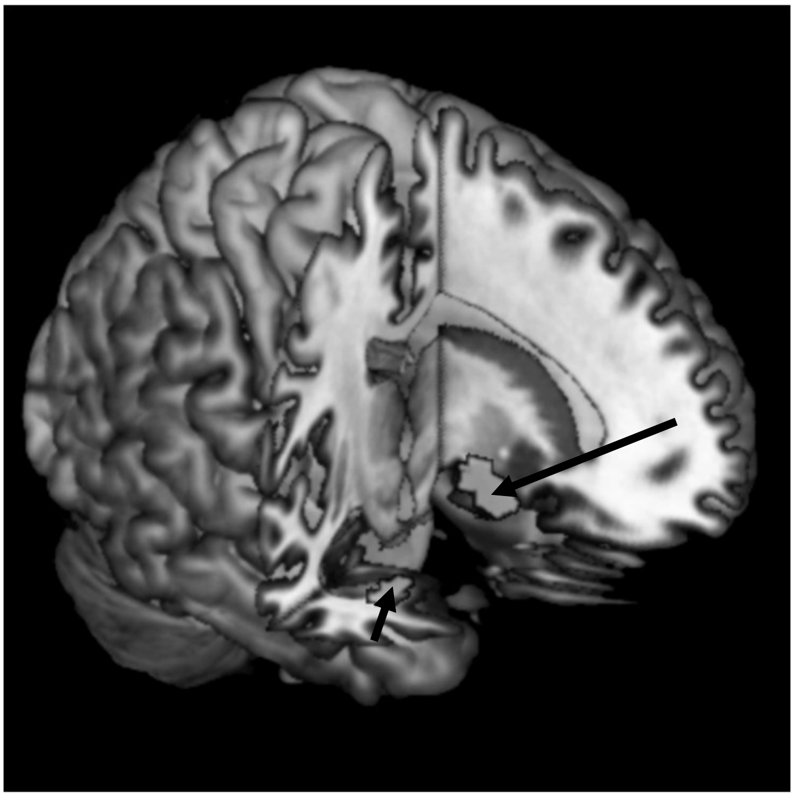
Notes. Pictures were derived from the Faces Database; Abbreviations: sec = seconds.

Imaging data acquisition. Magnetic Resonance imaging (MRI) data were acquired on a 3 Tesla Siemens Magnetom Tim Trio MRI system (Siemens, Erlangen, Germany) at the Berlin Center for Advanced Neuroimaging at the Charité – Universitätsmedizin Berlin, Germany. The visual paradigm was presented via a video projector on a mirror system. Functional images were collected using axial aligned T2*-weighted gradient echo planar imaging (EPI) sequences (33 slices, time to repeat (TR) = 2 s, time to echo (TE) = 30 ms, flip angle = 78°, field of view (FoV) = 192 x 192, matrix size = 64 x 64, voxel size = 3 x 3 x 3 mm^3). Moreover, a T1-weighted three-dimensional magnetization prepared rapid gradient echo (MPRAGE) sequence with an isotropic spatial resolution of 1mm^3 was applied (192 sagittal slices, TR = 1900 ms, TE = 2.52 ms, flip angle = 9°, FoV = 256 x 256, matrix size = 256 x 256).

FMRI data analyses. Images were processed and analyzed using the Statistical Parametric Mapping software package (SPM8, Wellcome Trust Centre for Neuroimaging, London, UK; http://www.fil.ion.ucl.ac.uk/spm). Briefly, EPIs were corrected for head motion and the individual MPRAGE images were coregistered to the mean image obtained from motion correction as well as segmented using the unified segmentation algorithm. EPIs were transformed into the stereotactic normalized standard space of the Montréal Neuroimaging Institute (MNI) using the normalization parameters obtained from segmentation and spatially smoothed with a 3D Gaussian kernel of 7 mm full width at half maximum.

For the preprocessed fMRI data a two-stage mixed effects model was applied. In the first stage, individual general linear models (GLMs) were estimated containing separate regressors of the different conditions: fearful, happy, angry and neutral young faces, fearful, happy, angry and neutral adult faces, shapes as well as the regressors of no interest: cue, button press and the six rigid body movement parameters. In the second stage, the single subjects' contrast images were entered into a within subject analysis of variance (ANOVA). For this analysis, only angry young and adult faces were of interest. Therefore, we further analyzed the differential contrast images young angry > young neutral and adult angry > adult neutral. Due to our strong a-priori hypothesis regarding differential findings within the amygdala, we conducted a region-of-interest analysis (ROI) by using the Automated Anatomical Labeling (AAL) brain atlas (cf. *Tzourio-Mazoyer* et al. 2002). BOLD (blood oxygenation level dependent) parameter estimates from the bilateral amygdala ROI were extracted using the VOI eigenvariate function in SPM8 and employed in the Structural Equation Model (see Figure 2).

Figure 2. Display of the used Regions-of-interest (ROI) in bilateral amygdala. ROI were defined using the Automated Anatomical Labeling Atlas (AAL)



3.4 Statistical Measures

Teachers as Positive Motivators (TPM). This subscale is part of the Relationship and Motivation (REMO) Scale (cf. *Raufelder* et al. 2013) and consists of six items (α = .81). Students were asked to answer statements such as "I will make more of an effort in a subject when I think the teacher believes in me" or "When a teacher helps me, I try to do well in the subject" on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree).

Peers as Positive Motivators (PPM). This subscale is also part of the REMO Scale (cf. *Raufelder* et al. 2013) and consists of nine items such as "When my friends learn, I am also motivated to learn more" or "My friends and I motivate each other to make an effort at school" are answered on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree) (α = .86).

Stress. In order to assess students' perceived stress, a German version (cf. *Wolf* 1991) of the perceived stress scale (PSS) developed by *Cohen/Kamarck/Mermelstein* (1983) was used (α = .87). Participants were asked to answer 9 questions on a 5-point Likert scale (1 = "never"; 5 = "very often") about how often they felt and behaved a certain way during the last month (e.g., “How often during the last month did you feel nervous and stressed”).

Loneliness. Students’ perceived loneliness was assessed with a German version (cf. *Schwab* 1997) of the UCLA Loneliness Scale (cf. *Russell* 1996). 10 items (e.g., “How often do you feel completely alone?”) were rated on a 4-point Likert scale (1 = “never” to 4 = “always”; $\alpha = .89$).

Depression. A German version (cf. *Gräfe* et al. 2004) of the Personal Health Questionnaire Depression Scale (PHQ-9) developed by *Kroenke/Spitzer/Williams* (see 2001; *Kroenke* et al. 2009) was used to assess students’ feelings of depression. 8 items such as “How often during the past 2 weeks were you bothered by feeling down, depressed, or hopeless“ were rated on a 5-point Likert scale (1= “not at all” to 5 = “nearly every day”) ($\alpha = .84$).

3.5 Statistical Analyses

Confirmatory Factor Analysis (CFA). Prior to conducting structural equation modeling (SEM), a confirmatory factor analysis (CFA), conducted with Mplus, was performed to evaluate the proposed measurement model. As some studies have shown that a larger number of indicators per factor negatively affect the model fit (cf. *Ding/Velicer/Harlow* 1995; *Wang/Wang* 2012) and as the sample size is relatively small, the number of items was reduced: low- and/or cross-loading items ($\alpha < .45$) were excluded from our analysis. However, a minimum of three indicators per factors is usually required even in a multifactor CFA model (cf. *Velicer/Fava* 1998; *Wang/Wang* 2012). Therefore, five three-item latent variables, each representing a single construct, were evaluated.

Structural Equation Modeling (SEM). Data were analyzed with Mplus version 7.0 (cf. *Muthén/Muthén* 2012) by applying maximum likelihood estimation to assess the predicted relations among the variables of interest. To account for missing data, models were estimated with full information maximum likelihood (FIML). Model fit was estimated in Mplus using four primary fit indices as recommended by *Hu/Bentler* (1999): Chi-Square Test of Model Fit (χ^2), Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Standardized Root Mean Square Residuals (SRMR).

4 Results

4.1 Correlations

The correlation analysis revealed significant positive relations between PPM and both students’ BOLD response in the amygdala to angry peer faces ($r = 0.30$, $p < .05$) and angry teacher faces ($r = 0.24$, $p < .05$), whereas TPM solely correlated with angry teacher faces ($r = 0.27$, $p < .05$). In addition, a strong positive correlation between TPM and depression has been identified ($r = 0.41$, $p < .001$). In contrast, there was no significant association between PPM and stress, loneliness and depression, or between TPM and both loneliness and stress. Interestingly, students’ neural processing of angry peer faces was negatively related to stress ($r = -0.27$, $p < .05$), whereas students' neural processing of angry teacher faces was positively related to loneliness ($r = 0.30$, $p < .05$) and marginal related to depression ($r = 0.22$, $p = .069$). Finally, depression was positively associated with stress ($r = 0.44$, $p < .001$) and loneliness ($r = 0.26$, $p < .05$). In contrast, there was no significant association between stress and loneliness.

Table 1. Summary of means (M), standard deviations (SD), and intercorrelations of adolescent students' scores on the variables of interest

Measure	2	3	4	5	6	7	M	SD	Range
1. PPM	.41**	.30*	.24*	–.18	.00	.11	2.62	.69	1-4
2. TPM	—	.23	.27*	.11	.18	.41**	3.09	.58	1-4
3. P-Anger		—	.19	–.27*	.11	–.08	.03	.44	—
4. T-Anger			—	.07	.30*	.22	.02	.41	—
5. Stress				—	.17	.44**	2.66	.75	1-5
6. Loneliness					—	.26*	2.17	.73	1-4
7. Depression						—	2.31	1.16	1-5

Note. All measures are standardized. *p< .05; **p < .001
PPM = peers as positive motivators, TPM = teachers as positive motivators, P-ANGER = peer faces showing anger (FMRI task), T-ANGER = teacher faces showing anger (FMRI task).

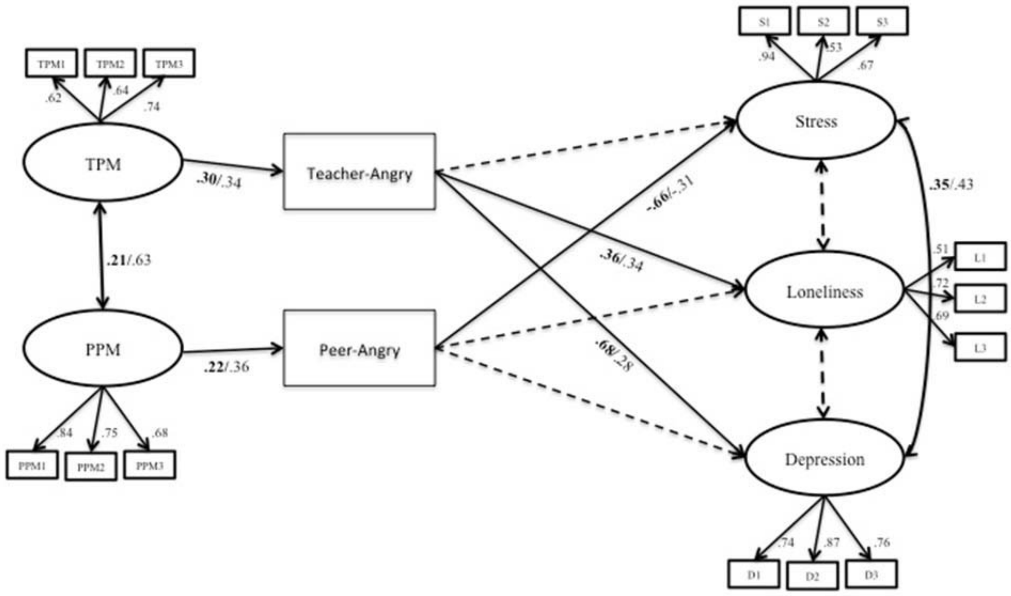
4.2 Structural Equation Modeling (SEM)

CFA. In preparation of the SEM, a CFA was conducted to test the measurement model. The indices indicated a satisfactory fit for the model (χ^2 (110) = 146.229, $p = .012$, $CFI = .91$, $RMSEA = .06$ (.02-.09), $SRMR = .11$). As the SRMR value is strongly affected by sample size, it is not optimal in the present small sample (cf. *Fan/Thompson/Wang* 1999).

Structural Equation Modeling. The SEM included (1) direct paths from peers as positive motivators (PPM) to the amygdala response to angry peer faces and from teachers as positive motivators (TPM) to the amygdala response to angry teacher faces, as well as (2) direct paths from both neural responses to angry peer and teacher faces on stress, loneliness and depression. The model fit was satisfactory (χ^2 (108) = 138.348, $p = .026$, $CFI = .91$, $RMSEA = .06$ (.02-.08), $SRMR = .10$). Again, the SRMR value is not optimal due to the relatively small sample size (cf. *Fan/Thompson/Wang* 1999).

First, the direct effects between PPM and student's neural processing of peers' angry faces ($B = .22$, $\beta = .36$, $SE = .08$, $p = .009$) as well as between TPM and student's neural processing of teachers' angry faces ($B = .30$, $\beta = .34$, $SE = 0.13$, $p = .020$) were found to be significant. Second, the direct effects between student's neural response to peers' anger and their perceived stress ($B = -.66$, $\beta = -.31$, $SE = .30$, $p = .031$) and between student's neural response to teachers' anger and loneliness (B = .36, β = .34, SE = .18, p = .052) and depression (B = .68, β = .28, SE = .34, p = .043) were found to be significant. In contrast, neither the direct effect between student's neural processing of peers' angry faces and loneliness and depression nor the direct effect between student's neural processing of teachers' angry faces and stress were found to be significant (see Figure 3).

Figure 3. Structural Equation Modeling



Notes. Significant effects shown as first unstandardized coefficients (B), second standardized coefficients (β), factor loadings are standardized. Bold pathways are significant at $p < 0.05$ level, dotted pathways are not significant. TPM = teachers as positive motivators, PPM = peers as positive motivators, Teacher-Angry = teacher faces showing anger (fMRI task), Peer-Angry = peer faces showing anger (FMRI task).

5 Discussion

The current interdisciplinary study aimed to examine the role of peers and teachers as motivators on adolescents' emotional processing in the amygdala considering effects on stress, loneliness and depression. Following a multi-method design combining quantitative and experimental neuroimaging research, the results underline a strong association between these variables.

In detail and according to hypothesis I, a positive relation has been identified between students' perception of peers and teacher as positive motivators and their activation level in the amygdala while watching angry peer and teacher faces. In other words, the more important peers and teachers are for adolescent students as source of motivation, the higher their amygdala activation. Furthermore, the results of the correlation analyses have shown that students' amygdala activation while watching angry teacher faces is strongly associated with loneliness. In contrast, there was only a marginal association between the amygdala activation for angry teacher faces and depression, and a non-significant association between the amygdala activation for angry teacher faces and stress. Contrary to our hypothesis, adolescent students' amygdala activation while watching angry peer faces was negatively associated with their perceived stress. This might be due to the fact that students, who perceive their peers as important source of motivation might be used to better deal with stressful situations (e.g., complexity within peer interactions). Unfortunately, the construct of peers as positive motivators (PPM) does not allow interpretations regarding for instance peer support or rejection. Therefore, future research that examines these facets of peer relationships in detail is warranted.

Interestingly, TPM was highly correlated with depression. That means, the more adolescent students perceive their teachers as positive motivators, the more they report feelings of depression. This might be explained through students' pressure to fulfill the expectation of the teacher going in line with a teacher dependency. In other words, giving support on the one hand and creating dependency on the other hand seems to be the underlying divergent nature of students' socio-motivational relationships with teachers. These results are in line with findings from *Sabol/Pianta* (2012), who showed that students reporting close and supportive relationships had lower rates of school avoidance, anxiety, and social withdrawal, whereas students reporting dependent relationships had higher rates of negative social outcomes and exhibiting behavioral problems at school (cf. *Pianta/Nimetz* 1991; *Sabol/Pianta* 2012). However, further research is necessary to examine these diverse facets of teacher-student relationships in detail.

Our second hypothesis has been confirmed as students' perception of peers as positive motivators as well as students' perception of teachers as positive motivators predicts the amygdala response. In other words, the more students perceive their peers as positive motivators, the higher their activity in response to angry peer faces in the amygdala. The same is true for teachers: the more students perceive their teachers as positive motivators, the stronger their amygdala response to angry teacher faces. As mentioned above, these findings are in line with *Vuilleumir* (2009), who has shown that the amygdala activation to an external stimulus (e.g., angry peer and teacher faces) is higher if the stimulus is being considered as salient. Also – at least for the peer group – it confirms findings regarding a stronger neural response to negative stimuli in adolescents who are more sensitive to the peer group (cf. *Grosbras* et al. 2007).

Hypothesis III could only partly be confirmed as students' emotion processing of angry peer faces within the amygdala was identified as a negative predictor of stress. That means, the higher the activation rate in the amygdala, the less stressed the students are. As previous research has shown that stressful experiences in adolescence increase the vulnerability for developing psychiatric disorders later in life (cf. *Heim/Plotsky/Nemeroff* 2004), future research is necessary to test whether there is a possible buffering effect of peer support in accordance with *Cohen/Wills'* (1985) buffering hypothesis. Moreover, future studies should examine brain functional networks in order to include not only the amygdala, which is thought to be involved in evaluation processes of a stressor, but also regulation processes, e.g. via the prefrontal cortex (cf. *McEwen/Gianaros* 2010). These regulatory mechanisms might alleviate the interpretation of our findings. In contrast, high activation rates while watching angry teacher faces predicts loneliness and depression. This could imply that students who rely on their teachers as source of motivation, but perceive (constantly) negative emotions (e.g. anger) within their socio-motivational relationship with teachers, are at higher risk to report loneliness and depression. The finding of an increased amygdala activity associated with depression has been reported in earlier studies (cf. *Abler* et al. 2007; *Greening* et al. 2013). Our results point to a similar pattern on a sub-clinical level in adolescents. Certainly, feelings of loneliness and depression are common in adolescence and longitudinal studies have to test whether a higher amygdala activity is a vulnerability marker placing adolescents at a greater risk for psychopathological disorders.

6 Strength, Limitations and Future Directions

When interpreting the current findings, some limitations need to be considered. Firstly, the sample size is relatively small following psychological standards. However, in terms of neuroimaging studies the sample size is above average. Nevertheless, the findings should not be generalized to a broader population. Secondly, one might criticize the use of self-report measures. This might be due to the trend that negative attitudes toward self-report data have taken on unjustified proportions (cf. *Spector* 2006; *Chan* 2009). Thirdly, interpretations of fMRI data should be treated with caution. FMRI measures BOLD activity, which is an indirect measure of neural activity. Therefore, disentangling whether differences are physiological or neural is difficult. Still, fMRI is a more objective measure of what is happening in an individual than behavioral correlates such as questionnaires and combining these methods can be enriching. Furthermore, the study at hand focuses on a certain brain structure, therefore interpretations regarding brain network alterations cannot be drawn from the data and should be addressed in further studies. Fourthly, firm conclusions about the causal ordering of variables cannot be drawn since the data are cross-sectional in nature. Therefore, a longitudinal research design is warranted, which would additionally allow the investigation of inter- and intra-individual differences in students' development.

Despite these limitations, the present study extends the existing research on adolescents' socio-motivational relationships with peers and teachers by considering their neural emotion processing in the amygdala and its impact on stress, loneliness and depression following an interdisciplinary and method-plural research design. In conclusion, our results underline the benefits of positive peer relationships as well as emotional risk patterns within teacher-student relationships. Finally, the present findings can be adapted to existing prevention and intervention programs to strengthen supportive teacher and student relationships through for example social competence (cf. *Bradley* et al. 2012; *Hinsch/Pfingsten* 2007), which should be long-term established in the school context.

Notes

1 Emotions are not naturally positive or negative, they are in fact multidimensional constructs and evaluated by the subject (cf. *Kristjánsson* 2003; *Solomon/Stone* 2002).

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