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Original article

When compliments do not hit but critiques do: an fMRI study into self-esteem and self-knowledge in processing social feedback

Charlotte C. van Schie,[1,2] Chui-De Chiu,[3] Serge A. R. B. Rombouts,[1,2,4] Willem J. Heiser,[1,5] and Bernet M. Elzinga[1,2]

[1]Institute of Psychology, Leiden University, P.O. Box 9555, 2300 RB Leiden, The Netherlands, [2]Leiden Institute for Brain and Cognition, P.O.Box 9600, 2300 RC Leiden, The Netherlands, [3]Department of Psychology, The Chinese University of Hong Kong, Shatin, Hong Kong, [4]Department of Radiology, Leiden University Medical Centre, P.O. Box 9600, 2300 RC Leiden, The Netherlands, and [5]Mathematical Institute, Leiden University, P.O. Box 9512, 2300 RA Leiden, The Netherlands

Correspondence should be addressed to Charlotte C. van Schie, Institute of Psychology, Faculty of Social and Behavourial Sciences, Leiden University, P.O. Box 9555, 2300 RB Leiden, The Netherlands. E-mail: c.c.van.schie@fsw.leidenuniv.nl

Abstract

The way we view ourselves may play an important role in our responses to interpersonal interactions. In this study, we investigate how feedback valence, consistency of feedback with self-knowledge and global self-esteem influence affective and neural responses to social feedback. Participants ($N = 46$) with a high range of self-esteem levels performed the social feedback task in an MRI scanner. Negative, intermediate and positive feedback was provided, supposedly by another person based on a personal interview. Participants rated their mood and applicability of feedback to the self. Analyses on trial basis on neural and affective responses are used to incorporate applicability of individual feedback words. Lower self-esteem related to low mood especially after receiving non-applicable negative feedback. Higher self-esteem related to increased posterior cingulate cortex and precuneus activation (i.e. self-referential processing) for applicable negative feedback. Lower self-esteem related to decreased medial prefrontal cortex, insula, anterior cingulate cortex and posterior cingulate cortex activation (i.e. self-referential processing) during positive feedback and decreased temporoparietal junction activation (i.e. other referential processing) for applicable positive feedback. Self-esteem and consistency of feedback with self-knowledge appear to guide our affective and neural responses to social feedback. This may be highly relevant for the interpersonal problems that individuals face with low self-esteem and negative self-views.

Key words: social feedback; fMRI; self-concept; self-referential processing; self-esteem

Introduction

Feedback from others informs us about our social standing and whether the way we view ourselves is in line with the way others view us (Swann, 1982; Cross and Markus, 1999; Over, 2016). Processing and responding to social feedback is highly relevant for updating our self-concept as this allows us to learn and grow and adapt to our social environments (Markus and Cross, 1990; vanDellen *et al.*, 2011; Swann and Brooks, 2012). Our self-concept is not only shaped through interaction with others, it also shapes our responses to these interactions (Markus and

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Wurf, 1987; Chen et al., 2006). Our self-concept guides us in which feedback should be processed and which dismissed as irrelevant (Markus and Wurf, 1987; Ahern et al., 2015).

Two main components of the self-concept are relevant in the context of our social interactions, self-knowledge and global self-esteem (Campbell et al., 2003). Self-knowledge is accumulated through experiencing consistencies in information about our attributes (Swann and Brooks, 2012). People can more easily process information that is consistent with their self-knowledge (Higgins, 1987; Vignoles et al., 2006; Stinson et al., 2010). Inconsistent social feedback induces tension, anger and confusion, regardless of the valence of the feedback (Higgins, 1987; Stinson et al., 2010). Self-esteem is thought to emerge through setting standards for ourselves which may be derived from what others implicitly or explicitly expect of us (Shavelson et al., 1976; Higgins, 1987). The level of self-esteem is related to our sensitivity to social feedback. Individuals with low self-esteem tend to experience more and longer lasting distress after rejection compared to individuals with high self-esteem (Nezlek et al., 1997; Bernichon et al., 2003; Brown, 2010; Ford and Collins, 2013). Neuroimaging studies indicate that during social rejection lower self-esteem is associated with both decreased and increased activation in the medial prefrontal cortex (mPFC) and ventral anterior cingulate cortex (ACC), interpreted as decreased emotion regulation or increased social pain (Onoda et al., 2010; Somerville et al., 2010; Gyurak et al., 2012).

So far, most studies have focussed on how individuals respond to social feedback without taking into account whether the specific feedback is consistent with that individual's self-concept. For example, studies on social rejection have shown that individuals, quite obviously, do not like to be rejected and that this acutely lowers mood (Leary, 2005; Blackhart et al., 2009; Cacioppo et al., 2013; Rotge et al., 2015). Moreover, on a neural level, rejection induces a different activation pattern [inferior orbitofrontal cortex (OFC), anterior insula, ACC (pgACC, sgACC and aMCC) and caudate nucleus] (Cacioppo et al., 2013; Rotge et al., 2015) than acceptance (mPFC and vACC) (Somerville et al., 2006). Some recent findings also point to neural commonalities for both acceptance and rejection in the insula, dACC and mPFC, indicating that not only valence but also the social and self-relevancy of feedback is important (Achterberg et al., 2016; Dalgleish et al., 2017). The binary feedback provided to participants in conventional social feedback paradigms [e.g. being included or excluded (Onoda et al., 2010), or being liked or disliked by peers based on a photograph (Somerville et al., 2010)], does not allow to consider the relevance of self-knowledge. Eisenberger et al. (2011) did use personal feedback (e.g. presenting nouns such as lazy, annoying) and found that feedback which lowers self-esteem at that moment, increases activation in the dorsal ACC and anterior insula (Eisenberger et al., 2011). This novel paradigm allows for an assessment of the consistency between feedback and self-knowledge, though it was not done in that study.

Furthermore, no studies directly assessed which brain regions are involved in the processing of the (in)consistency of social feedback with an individual's self-knowledge. We postulate that the Cortical Midline Structures [CMS, i.e. mPFC, ACC, posterior cingulate cortex (PCC) and precuneus] may be involved in this process as they play a critical role in thinking about the self and whether information is relevant to the self (Fossati et al., 2003; Phan et al., 2004; Northoff et al., 2006; Moran et al., 2011; Bergstrom et al., 2015). More importantly, we postulate that consistency of social feedback may interact with valence of feedback and self-esteem. While individuals with high self-esteem possess a clear self-concept with predominantly positive attributes, the self-concept of individuals with low self-esteem consists of conflicting attributes (Campbell et al., 1996). Therefore, the threat from negative feedback to the self-concept, especially when inconsistent with self-knowledge, may be larger for individuals with low self-esteem as they may meet more difficulties refusing it (vanDellen et al., 2011).

In sum, previous experimental studies have shown that feedback has a particular strong impact when it is negative and inconsistent with our self-knowledge and that the impact may differ depending on self-esteem. Our knowledge is still limited in terms of shared and unique neural correlates of positive and negative feedback. So far, no studies have investigated how (in)consistency of social feedback with self-knowledge is processed in the brain. To provide a better understanding of how the self-concept affects our neural and affective responses to social feedback (idiosyncratic nouns with a negative, positive or intermediate valence), this study evaluates the role of valence, the (in)consistency between feedback and self-knowledge and self-esteem. To increase our understanding of the role of self-esteem on responses to social feedback, this study included participants along the full spectrum of global self-esteem, including participants with clinically low self-esteem (Schmitt and Allik, 2005; Korrelboom, 2011).

Methods

Participants

Female participants ($N = 46$) from the general population (age: $M = 29.6$, s.d. $= 9.5$, range 18–54 years) were included with a broad range of trait self-esteem (range 8–29, possible range 0–30), including 14 participants who reported clinically low trait self-esteem (cut-off < 18) (Rosenberg, 1965; Schmitt and Allik, 2005; Korrelboom, 2011). Education levels ranged from high school to university level (Table 1). Eleven participants reported one or two lifetime axis I disorder (Table 1). Uniquely, four participants[1] reported the use of medication (N by type): antidepressants $N = 1$ (SSRI: Sertraline 100 mg); sleep medication $N = 1$ (Lorazepam); and medication for physical ailments $N = 3$ [(Valsartan, Insulin, Ventolin (salbutamol), Foster (formoterol), and Levothyroxine]. Trait self-esteem was not related to age or education level but was related to the likelihood of having a lifetime axis I disorder (OR = 0.84, 95% CI 0.73–0.96).

Participants were recruited using online advertisements as well as local posters and flyers. We only included women as they may be more sensitive to social feedback (Stroud et al., 2002; Benenson et al., 2013). Exclusion criteria were incompatibility with the MRI scanner, current axis I disorder diagnosis and usage of benzodiazepines, antipsychotics or more than 20 mg of Oxazepam. Most participants were right handed ($N = 40$, 87%) (Table 1) (van Strien, 1992). Two participants were excluded from analyses because of scanner artefacts resulting in the sample of 46 participants described above.

Participants signed for their informed consent to participate in this study. The study was approved by the medical ethics committee of the Leiden University Medical Centre (P12.249) and was performed in accordance with the declaration of Helsinki and the Dutch Medical Research Involving Human Subjects Act (WMO).

1 Two participants took two kinds of medication for physical ailments, one participant took sleep medication as well as medication for high blood pressure, and one participant solely took SSRI medication.

Table 1. Demographic data ($N = 46$)

Variable	Mean (s.d.)/count (%)
Age (Years)	29.35 (9.7)
Education	
High school	3 (6.5%)
Vocational training (MBO)	22 (48%)
Higher education (HBO & University)	21 (46%)
Trait self-esteem (RSES)	20.65 (5.6)
State DERQ	
Handedness	7.93 (5.13)
Right handed (>7)	40 (87%)
Left handed (<−7)	2 (4%)
Ambidextrous (−7 − 7)	4 (9%)
Axis I Disorder (MINI-plus)	
Mood disorders	7 (15%)
Anxiety disorders	3 (6.5%)
PTSD	1 (2.2%)
ADHD	0
Substance abuse & addiction	0
Other disorders	2 (4.3%)

Social feedback task

Participants performed the social feedback task (SF task) in which they received evaluative feedback that putatively was given by another female participant who in reality was a confederate to the study. Preceding the SF task, the participant and the confederate were introduced and received instructions together. The participant was informed that she would receive personal feedback from the confederate based on a personal interview in the context of a study about forming impressions. The confederate was then ostensibly taken to another MRI scanner to give feedback on the personal interview. The participant was interviewed using personal questions and was confronted with three moral dilemmas (see Supplementary Material). The full interview was recorded using a voice recorder and was supposedly given to the confederate to base their evaluative feedback on.

The SF task was based on an existing social feedback-task (Eisenberger *et al.*, 2011). Two important modifications were made: only one feedback word was presented per trial to ensure that participants would focus on the content of this specific word and more feedback words ($N = 45$) were included to increase the number of trials without repeating feedback words. Participants performed the SF task whilst lying in an MRI scanner and were presented with 45 feedback words (see Supplementary Material), i.e. 15 negative (e.g. ‘arrogant’), 15 positive (e.g. ‘happy’) and 15 intermediate (e.g. ‘reserved’) nouns. The feedback was presented in random order with the condition that no consecutive trials could be of the same valence. However, to speed up computer randomization time the trials were split in two parts (23 and 22 trials) which were then merged resulting in possibly one trial being followed by the same valence. After each word the participant was asked how she felt right now (mood) responding on a scale of 1 (= really bad) to 4 (= really good) using scanner button boxes[2] attached to the legs. Figure 1 shows the timings and displays of one trial. Once outside the scanner participants rated all the feedback words in terms of applicability (scale: 1—‘not at all applicable to me’ to 4—‘very much applicable to me’) and valence (scale: −4—‘very negative’, to 0—‘neutral’, to 4—‘very positive’) and their general experience of the SF task and the confederate in four questions (Supplementary Table S1). Before debriefing a brief manipulation check interview was held (see Supplementary Material).

2 Participants used both hands to indicate their mood rating. This was not randomised and therefore pressing with the left hand is associated with negative mood and vice versa. This is visible as activation in the sensorimotor cortex (pre- and postcentral gyrus) in the contrasts on valence.

Measures and materials

Psychopathology

To assess lifetime and current Axis-I disorders based on DSM-IV the MINI-plus, a semi-structured interview (First *et al.*, 1997) was used by a trained psychologist (C.v.S.) who held the interview by telephone.

Trait self-esteem

The Rosenberg Self-Esteem Scale (RSES) measures the level of trait self-esteem using the sum of ten items that can be answered on a four point scale ranging from totally agree to totally disagree (Rosenberg, 1965). The Dutch translation has been well validated (Schmitt and Allik, 2005; Franck *et al.*, 2008). The reliability was good ($a = 0.89$).

Procedure

Participants were screened by phone and with online questionnaires on compatibility with the MRI scanner (e.g. no metal objects in their body), axis I disorders, and medication use. Moreover, participants filled out a handedness questionnaire (scale: −10 to 10) (van Strien, 1992). After screening and inclusion two appointments were made. During the first appointment participants signed informed consent, filled in a demographic form and the RSES and were prepared for the MRI scan session. During the second appointment, they performed the SF task in the MRI scanner. On average there were 20.0 (s.d. = 30.5) days between the administration of the RSES and the fMRI scan. The temporal stability of the RSES is quite good [test–retest reliability at 2 weeks = 0.84 (Fleming and Courtney, 1984; Pullmann and Allik, 2000)]. After the experiment participants were debriefed of the set-up of the experiment including the fake feedback and received a monetary reward of €30.

Data acquisition

The SF task was programmed in E-prime 2.0. MRI images were acquired using a Phillips 3.0 Tesla scanner equipped with a SENSE-8 channel head coil and situated as the Leiden University Medical Centre (LUMC). A survey scan and an initial resting state scan were completed first. T2*-weighted echo planar imaging (EPI) was used during the SF task with the following parameters: FOV RL: 220 mm, AP: 220 mm, FH: 114.68 mm; Matrix 80×80, Voxel size RL: 2.75 mm AP: 2.75 mm; Slice thickness 2.75 mm; Interslice skip 0.275 mm; 38 transverse slices in descending order; TE 30 ms, TR 2200 ms, Flip Angle 80°. Number of volumes ($M = 161.78$, s.d. = 19.04) varied as the SF task was self-paced. For registration purposes a four volume high resolution T2*-weighted EPI and a structural 3D T1 scan were acquired. The parameters for the T2 scan were: FOV RL: 220 mm, AP: 220 mm, FH: 168 mm; Matrix 112×112, Voxel size RL: 1.96 mm AP: 1.96 mm; Slice thickness 2.0 mm; 84 transverse slices; TE 30 ms, TR 2200 ms, Flip Angle 80°. The parameters for

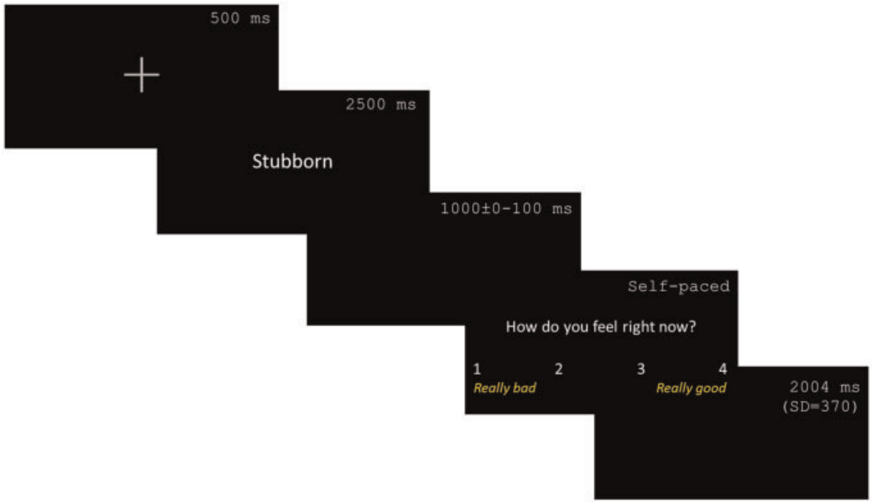

Fig. 1. Timings and displays of one trial in the SF task.

the 3D T1 scan were: FOV RL: 177.33 mm, AP: 224 mm, FH: 168 mm; Matrix 256×256, Voxel size RL: 0.88 mm AP: 0.87 mm; Slice thickness 1.20 mm; 140 transverse slices; TE 4.6 ms, TR 9.7 ms, Flip Angle 8°; Duration 4: 55 min. Scans were examined by a radiologist and no abnormalities were found.

Data pre-processing and analysis

Affective responses

Responses to the SF task were pre-processed using Excel 2010 and IBM SPSS statistics version 23 and analysed using R version 3.3.0 with the following packages: lme4 for multilevel analysis, psych for descriptive statistics and ggplot2 for creating figures (Wickham, 2009; R Core Team, 2013; Bates *et al.*, 2015). Multi-level analysis was used to analyse the affective responses during the SF task, to incorporate individualised trial based information. On the first level, the characteristics related to the feedback, i.e. valence and applicability, for each feedback word for each participant was specified. The second level consists of the trait characteristics of the individuals, i.e. trait self-esteem (RSES) (Hox, 2010). The intermediate valence was set as the reference category (intercept). Both mood and applicability ratings were recoded from 1, 2, 3, 4 to contrast values −3, −1, 1, 3 and RSES was centred on the sample mean. To be able to test for the significance of main and interaction effects, we constructed five models increasing in complexity adding first main and interaction effects of valence and applicability and finally adding trait self-esteem, see Table 2 for the construction of models 1–5.

Neural responses

Data were pre-processed using Feat v6.00 in FSL 5.0.7. The first 5 vol were discarded. A high pass filter of 80 s was used. Motion was corrected using MCFLIRT with 6 degrees of freedom (dof) and the middle volume as reference volume. No slice time correction was used but temporal derivatives were added in the model. Data were spatially smoothed with FWHM of 5 mm. Raw and pre-processed data were checked for quality, registration and movement. No participant moved more than 3 mm. For higher level analysis data were registered to the MNI152 2 mm template. The middle volume was registered to the high resolution T2 image using 6 dof. The Boundary-Based Registration algorithm was used for registration to the anatomical T1 scan. A linear 12 dof transformation was used for registration to the template.

On the individual analysis level, an event related design was applied where valence and applicability were simultaneously included in one model. For each valence, the onset and duration of each word was specified with equal weighting, resulting in three regressors for valence. To investigate the impact of the applicability of the feedback, parametric modulation analysis was used where for each valence category each trial was modulated with the recoded applicability ratings resulting in another three regressors. The onset and duration of the mood question was modelled as a regressor of no interest. The bold response was convolved with the double-gamma HRF function. Six motion parameters indicating rotation and translation and mean time series of white matter and cerebrospinal fluid were added as confound regressors (Birn *et al.*, 2006; McCabe *et al.*, 2011; Cheng and Puce, 2014). T-contrasts were formulated to compare negative and positive feedback to each other and to intermediate feedback, to test the main effect of applicability, and the interaction between valence (neg/pos) and applicability. To test the moderating role of trait self-esteem on valence and applicability, a group-level model containing constant, centred RSES and one group variance was used. A mixed effects model with the FLAME1 method was used for group level inference. Data were cluster corrected with $Z > 2.3$ and cluster $P < 0.05$. This cluster correction using the FLAME 1 method has been shown to be a conservative method where the amount of false positives stays within limits (Eklund *et al.*, 2016). In addition, we used mood as parametric modulator in one model with valence to replicate the analysis of Eisenberger *et al.*, (2011). These results can be found in Supplementary Table S2.

For the labelling of peak voxels, the Harvard–Oxford structural atlas was used for cortical and subcortical regions (Frazier *et al.*, 2005; Desikan *et al.*, 2006; Makris *et al.*, 2006; Goldstein *et al.*, 2007), and Mars connectivity-based parcellation for temporoparietal junction (TPJ) and inferior parietal lobule (IPL) areas (Mars *et al.*, 2011, 2012). For cerebellum coordinates, the cerebellar atlas was used (Diedrichsen *et al.*, 2009). To indicate Brodmann areas, Talairach Daemon labels were used (Lancaster *et al.*, 2000).

Table 2. Models predicting mood after each feedback word based on valence and applicability of the feedback and trait self-esteem (the intra-class correlation = 0.12)

Model of mood after feedback	AIC	BIC	Log likelihood	χ^2 (df), P
Null model: random intercepts only	8383.1	8400.0	−4188.6	
Model 1: valence	7132.4	7160.5	−3561.2	$\chi^2(2) = 1254.75$, $P < 0.001$
Model 2: applicability	6979.3	7013.1	−3483.7	$\chi^2(1) = 155.08$, $P < 0.001$
Model 3: valence×applicability interaction	6976.1	7021.2	−3480.1	$\chi^2(2) = 7.17$, $P = 0.028$
Model 4: random effects of valence and applicability	6620.9	6716.6	−3293.5	$\chi^2(9) = 373.20$, $P < 0.001$
Model 5: trait self-esteem and all two and three-way interactions	6614.3	6743.8	−3284.2	$\chi^2(6) = 18.58$, $P = 0.005$

Notes: Adding applicability of the feedback and its interaction with valence (models 2 and 3) and random effects of applicability and valence (model 4) significantly improved the model. Adding trait self-esteem and all two and three-way interactions (model 5) was an improvement compared to model 4.

Results

Validation of the SF task

The 45 feedback words used in the SF task were chosen from 96 previously validated words (e.g. Eisenberger *et al.*, 2011) that were rated for their valence on a scale of −4 to 4 in a pilot study ($N = 19$, age $M = 29.6$, s.d. = 10.0). The 15 most positive and negative rated feedback words that were not contradictory in meaning were chosen. Intermediate feedback consisted of the words with a score close to zero and smallest standard deviation. The participants' mean valence ratings of feedback were in accordance with the pilot sample [$r(43) = 0.98$, $P < 0.001$]. Multilevel analysis showed that negative feedback ($M = -2.65$, s.d. = 1.53, $t = -34.19$) was rated as more negative than intermediate feedback ($M = 0.22$, s.d. = 2.06), which was rated as less positive than positive feedback ($M = 3.17$, s.d. = 1.15, $t = 35.17$) [Valence: $\chi^2(7) = 2583.30$, $P < 0.001$]. Even though the range of applicability ratings was the same for each valence (i.e. −3 to 3), positive feedback ($M = 1.70$, s.d. = 1.33, $t = 9.23$) was rated as more applicable than intermediate feedback ($M = 0.66$, s.d. = 1.95) which was rated as more applicable than negative feedback ($M = -1.75$, s.d. = 1.64, $t = -20.33$) [Valence: $\chi^2(7) = 1295.53$, $P < 0.001$]. Trait self-esteem did not affect applicability ratings of negative ($b = -0.03$, SE = 0.02, $t = -1.41$) or positive feedback ($b = 0.03$, SE = 0.02, $t = 1.67$) compared to intermediate feedback [Valence×Trait self-esteem: $\chi^2(2) = 4.99$, $P = 0.08$]. There were no multicollinearity issues (all VIF's < 3.90) in the models below. Regarding the manipulation check, almost all participants ($N = 42$, 91%) indicated they believed the feedback of the confederate was real. Regarding the general experience of the SF task, participants who thought that the feedback described them well, also held a more positive view of the confederate [$b = .44$, $t(43) = 3.84$, $P < 0.001$] (Supplementary Table S1). This relationship was moderated by trait self-esteem [$b = 0.07$, $t(43) = 3.66$, $P = 0.001$] and self-esteem was negatively related to liking the confederate [$b = -0.94$, $t(43) = -2.64$, $P = 0.012$], indicating that participants with lower self-esteem held a more positive view of the confederate regardless of whether the feedback described them well.

Affective responses to social feedback

Valence and applicability

The model containing all main effects and two- and three-way interaction effects of valence, applicability and trait self-esteem was significant [$\chi^2(6) = 18.58$, $P = 0.005$]. Effect parameters reported here are derived from this model (model 5) (Table 2). First, we discuss how valence and applicability of the feedback and their interaction influenced participants' mood. Receiving negative feedback ($b = -1.00$, SE = 0.11, $t = -9.22$) decreased mood compared to receiving intermediate feedback [b (intercept) = 0.45, SE = 0.13, $t = 3.60$], whereas positive feedback compared to intermediate feedback enhanced mood [$b = 1.20$, SE = 0.13, $t = 9.04$] (Figure 2A). As hypothesized, feedback that was rated as less applicable was associated with decreased mood, regardless of valence ($b = 0.28$, SE = 0.03, $t = 9.07$). Moreover, the interaction between valence and applicability, indicated that negative and intermediate feedback are even more detrimental for mood when they are less applicable, whereas mood after positive feedback is not moderated by applicability as much ($b = -0.11$, SE = 0.04, $t = -2.65$) (Figure 2A).

Trait self-esteem

On top of the findings reported above, there was a main effect for trait self-esteem ($b = 0.05$, SE = 0.02, $t = 2.01$), indicating that lower levels of trait self-esteem were related to a lower mood overall. Furthermore, level of trait self-esteem moderated mood after negative and intermediate feedback, but not after positive feedback ($b = -0.05$, SE = 0.02, $t = -1.89$), indicating that negative and intermediate feedback has a more detrimental effect on mood for participants with lower trait self-esteem compared to participants with high self-esteem. Finally, the three-way interaction between trait self-esteem, applicability and negative feedback showed that participants with lower self-esteem report an additional decrease in mood after negative feedback which is not applicable, whereas participants with higher self-esteem are less affected by inapplicable negative feedback ($b = -0.01$, SE = 0.01, $t = -1.95$) (Figure 2B and Supplementary Table S3 for all effect parameters).

Neural responses to social feedback

Valence

In line with our hypotheses, we found that negative feedback compared to positive feedback was related to increased activation in the bilateral anterior insula, bilateral orbitofrontal cortex (OFC), ACC (aMCC, not pgACC and sgACC), bilateral caudate nucleus, and additionally in the left inferior frontal gyrus (IFG), left superior and middle frontal gyrus, left precuneus and left the lingual gyrus (Figure 3A). For cluster sizes and peak voxels, see Table 3.[3] Compared to intermediate feedback, negative feedback

3 As there were many peak voxels, only a selection representative of the cluster is reported here. All peak voxels can be found in Supplementary Table 4.

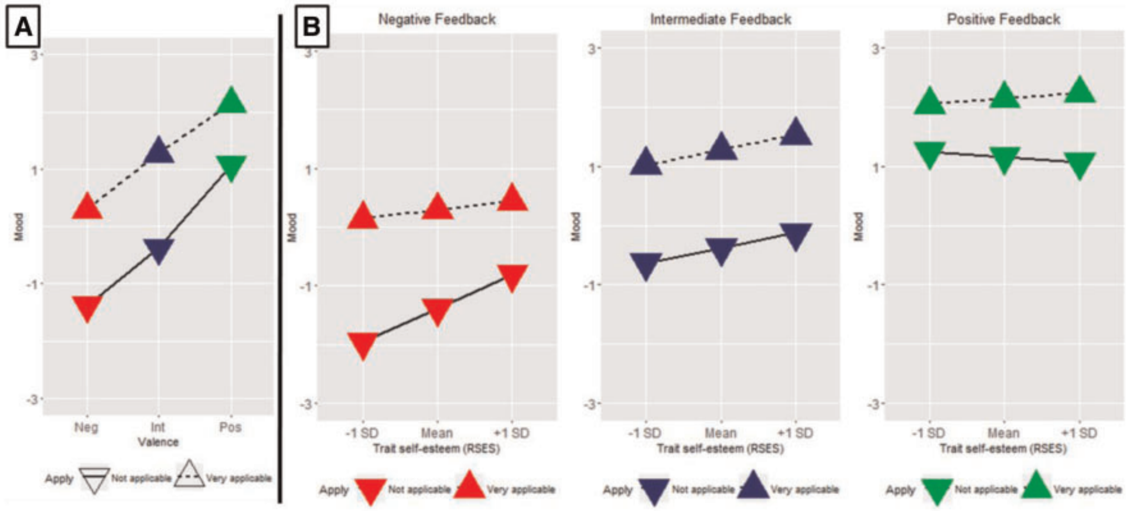

Fig. 2. (A) Mean mood ratings for negative (red), intermediate (blue) and positive (green) feedback which is not or very applicable and (B) mean mood ratings further split by three levels of trait self-esteem (1 s.d. below the mean, mean level and 1 s.d. above the mean).

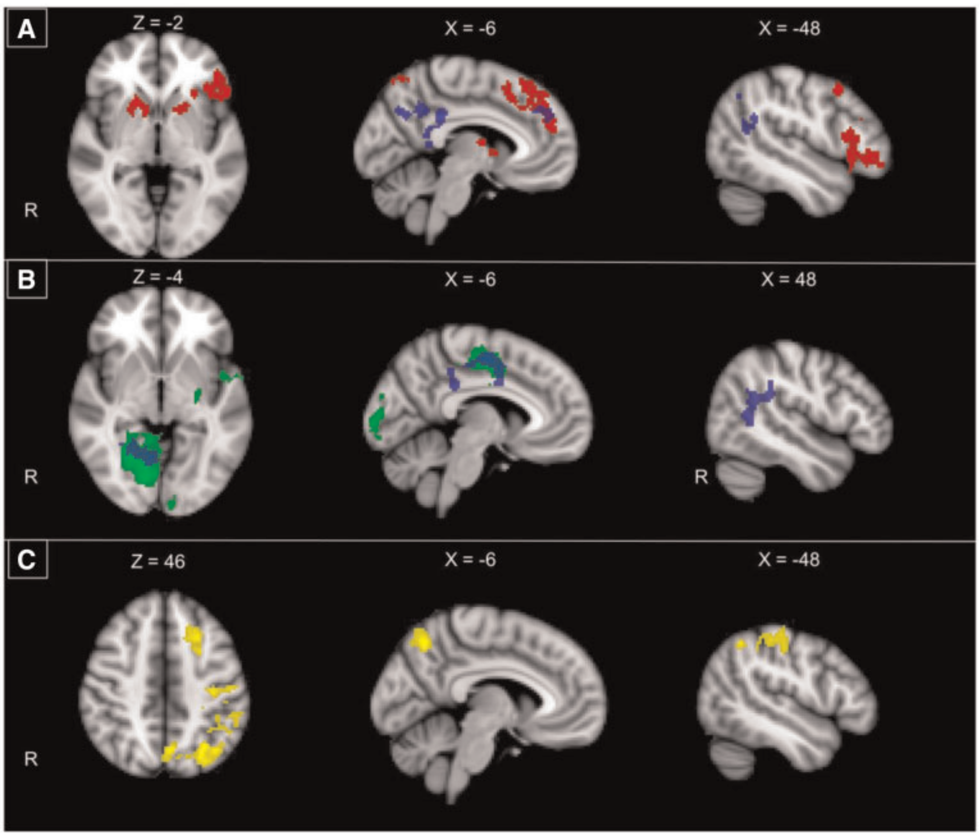

Fig. 3. Neural activation related to valence and applicability of the feedback, cluster threshold with $z = 2.3$ and cluster $P < 0.05$. To facilitate comparability of results, similar coordinates have been used for visualisation. (A) Activation related to negative feedback compared to positive (red) and intermediate (blue) feedback. (B) Activation related to positive feedback compared to negative (green) and intermediate (blue) feedback. (C) Activation positively related to applicability of feedback.

was related to activation in the precuneus, PCC, left superior frontal gyrus, left frontal pole, left lateral occipital cortex and left TPJ. Positive feedback compared to negative feedback elicited activation in the ACC, PCC, cuneus, left posterior insula, and right lingual gyrus (Figure 3B; Table 3). Compared to intermediate feedback, positive feedback was related to increased activity in the PCC, precuneus, right TPJ, left posterior insula and right lingual gyrus.

Table 3. Neural correlates of feedback valence

Contrast	Cluster size	Cluster *P*-value	Label peak voxels	Voxel test value	MNI coordinates		
				Z	X	Y	Z
Negative > positive	2987	<0.001	R Postcentral gyrus	5.67	38	−22	48
			R Lateral occipital cortex, SPLD, BA7	5.25	18	−70	56
	1847	<0.001	R Caudate	4.36	10	12	2
			L OFC	4.13	−38	28	0
			L IFG	3.92	−56	22	16
			L Caudate	3.83	−12	2	16
			L Insula	3.71	−28	22	0
	1174	<0.001	L Superior frontal gyrus, BA8	4.47	−2	46	38
			L Frontal poleBA9	3.59	−18	54	26
			R Paracingulate gyrus, ACC	3.47	14	20	36
	912	<0.001	R Crus I	5.19	28	−80	−34
			R Crus II	3.23	12	−90	−40
	368	0.027	L Middle frontal gyrus	4.30	−42	14	44
			L Middle frontal gyrus, BA6	2.50	−38	4	58
Negative > intermediate	1695	<0.001	L PCC	3.93	−6	−36	32
			Precuneus, BA7	3.90	0	−52	40
			R PCC	3.85	2	−38	24
	1422	<0.001	R Precentral gyrus	4.77	36	−20	56
			R Postcentral gyrus, IPLB, BA3	4.74	40	−22	52
	809	<0.001	L Frontal pole	4.33	−22	42	22
			L Frontal pole, BA10	3.79	−24	56	20
			L Superior frontal gyrus	3.48	−8	50	32
	523	0.003	L Lateral occipital cortex	3.62	−38	−78	32
			L Lateral occipital cortex, BA19	2.99	−34	−76	42
	399	0.016	L Angular gyrus	3.69	−42	−50	30
			L Lateral occipital cortex	3.26	−58	−62	14
Positive > negative	4137	<0.001	L Precentral gyrus, BA4	5.91	−38	−18	56
			L Postcentral gyrus	5.31	−38	−26	56
	3872	<0.001	R Lingual gyrus, VI	5.40	18	−66	−12
			R Temporal occipital fusiform cortex, VI	5.32	22	−58	−16
	644	0.001	L ACC, BA24	4.82	−6	−4	46
			L ACC	4.76	−6	−2	42
	554	0.002	L Occipital pole	4.56	−14	−96	10
			L Occipital pole, BA17	3.98	−14	−94	4
			L Occipital pole, BA18	2.78	0	−96	2
Positive > intermediate	2407	<0.001	L Postcentral gyrus, BA1	5.44	−50	−22	58
			L Precentral gyrus, BA4	5.14	−36	−16	64
	1599	<0.001	R Temporal occipital fusiform cortex, VI	4.74	28	−56	−20
			R Lingual gyrus, V	4.21	6	−60	−6
	1560	<0.001	L Juxtapositional lobule	4.70	−2	−12	52
			R Precuneus, BA7	4.02	10	−66	38
			R PCC	4.01	12	−34	36
	692	<0.001	R MTG	3.57	48	−54	8
			R Angular gyrus, TPJa, TPJp, BA40	3.33	56	−46	24
	607	0.001	L Heschl's gyrus, BA41	4.00	−46	−22	12
			L Central opercular cortex, BA40	3.94	−48	−22	16
			L Insula	3.52	−36	−16	4

Note: All clusters with selected peak voxels, cluster corrected $z = 2.3$, cluster $P < .05$

Applicability

Less applicable feedback, regardless of valence, was related to decreased activation in the left precuneus (Figure 3C and the left superior and middle frontal gyrus; Table 4). There were three-way interaction effects with valence and trait self-esteem, see below.

Trait self-esteem

In line with the affective results and our hypothesis, we found that level of trait self-esteem moderated the activation for negative feedback. Lower self-esteem was related to decreased activation in the left middle temporal gyrus (MTG) (Table 5 and Figure 4A). During positive feedback, lower self-esteem was related to decreased activation in the bilateral mPFC, insula, ACC and PCC. Moreover, lower self-esteem was related to decreased left TPJ activation in response to more applicable feedback.

In line with the effects on mood, we found a three-way interaction of trait self-esteem, applicability and negative feedback in the PCC and precuneus (Figure 4C). Participants with higher self-esteem showed increased PCC and precuneus activation for

Table 4. Neural correlates of feedback applicability

Contrast	Cluster size	Cluster P-value	Label peak voxels	Voxel test value	MNI coordinates		
				Z	X	Y	Z
Applicability (positive relation with activity)	2417	<0.001	L Lateral occipital cortex, BA19	4.02	−28	−70	48
			L Precuneus	3.94	−6	−66	50
			L Superior parietal lobule	3.88	−32	−58	54
	464	0.006	L Superior frontal gyrus	3.68	−26	20	50
			L Middle frontal gyrus, BA6	3.40	−26	8	48
			L Superior frontal gyrus, BA8	3.38	−18	28	40
Applicability (negative relation with activity)	1049	<0.001	R Precentral gyrus	4.19	56	−8	46
			R Postcentral gyrus, IPLB, IPLA	3.77	50	−20	46
	917	<0.001	L VI	3.66	−28	−56	−24
			L Occipital fusiform gyrus, VI	3.58	−18	−68	−14
			L Lingual gyrus	3.50	−12	−56	−8
Applicability×Neg	336	0.039	L Precentral gyrus, BA4	3.98	−38	−20	58
			L Postcentral gyrus, BA3	2.36	−26	−30	52
Applicability×Pos	–						

Note: All clusters with selected peak voxels, cluster corrected $z = 2.3$, cluster $P < 0.05$. The interaction effect between applicability and negative valence did not reach significance when adding handedness.

more applicable negative feedback and conversely, decreased PCC and precuneus activation for less applicable negative feedback (Table 5; Figure 4D). On the other hand, for participants with low self-esteem applicability of negative feedback was less related to PCC and precuneus activation. Finally, there was a three-way interaction between trait self-esteem, applicability and positive feedback in the left MTG and TPJ (Figure 4C). Participants with lower self-esteem showed decreased activation in the left MTG and left posterior TPJ in response to positive applicable feedback (Table 5; Figure 4D). The TPJ area overlapped with activation found for applicability moderated by trait self-esteem (Figure 4B). The TPJ and MTG activation may indicate other-referential thinking.

Confounds

The use of psychotropic medication (on/off) and whether participants believed the feedback as coming from the confederate (yes/no) were additionally taken into account in the affective analyses and did not change the results. Even when removing participants who did not believe in the experimental manipulation ($N = 4$) or took medication ($N = 4$), the same affective results remained. In the neural analyses, the degree of left or right handedness was taken into account as well. Medication and believing status led to minor changes in neural findings. When adding handedness or removing left-handed and ambidextrous participants ($N = 6$) or participants that took medication, the three-way interaction between applicability, self-esteem and positive valence failed to reach significance. This effect altered when removing participants who did not believe in the experimental manipulation to the more posterior part of both the TPJ and MTG. Furthermore, removing participants based on handedness had an impact on the interaction effect between self-esteem and negative feedback and self-esteem and applicability. Finally, the three-way interaction between applicability, self-esteem and negative valence failed to reach significance when removing participants based on believing status.

Discussion

In this study, we simultaneously investigated the influence of social feedback valence (negative, intermediate and positive), consistency of the feedback with self-knowledge, and self-esteem and showed that all are important in affective and neural responses to social feedback.

In terms of valence, we found that negative feedback, in line with social rejection studies, decreased mood and activated the bilateral anterior insula, OFC and caudate nucleus and ACC (aMCC) (Blackhart *et al.*, 2009; Cacioppo *et al.*, 2013; Rotge *et al.*, 2015). In addition, negative feedback activated the bilateral IFG, PCC, left precuneus, left lingual gyrus, left TPJ and left middle frontal gyrus. These areas are commonly found in relation to self- and other-referential thinking (Northoff *et al.*, 2006; Schurz *et al.*, 2014). The IFG, PCC and precuneus are part of the CMS and are important for evaluating self-relevant stimuli (Northoff *et al.*, 2006). This is in line with the fact that many participants indicated at debriefing that they were reflecting on their answers during the interview. The TPJ is implicated in self- but even more in other-referential thinking and is reliably found in the Theory of Mind network for thinking about the mental states of others (Molnar-Szakacs and Uddin, 2013; Schurz *et al.*, 2014). As many participants also indicated at debriefing that they were pondering about the choices of the confederate, this could point to participants thinking about the person evaluating them. Our paradigm, using more personal feedback and a confederate, seems to elicit more self- and other referential thinking than paradigms using impersonal rejection feedback such as the Cyberball game.

The insula and ACC activation we found in relation to negative feedback is not necessarily rejection specific as recent studies have pointed to common neural activation for both rejection and acceptance in these areas (Achterberg *et al.*, 2016; Dalgleish *et al.*, 2017). We found that positive feedback, in line with acceptance feedback, enhanced mood and activated the ACC (pMCC), left posterior insula as well as PCC, cuneus, the right lingual gyrus, right MTG and right TPJ (Somerville *et al.*, 2006; Blackhart *et al.*, 2009). Both feedback valences activated the ACC and insula; however, each valence activated a different part.

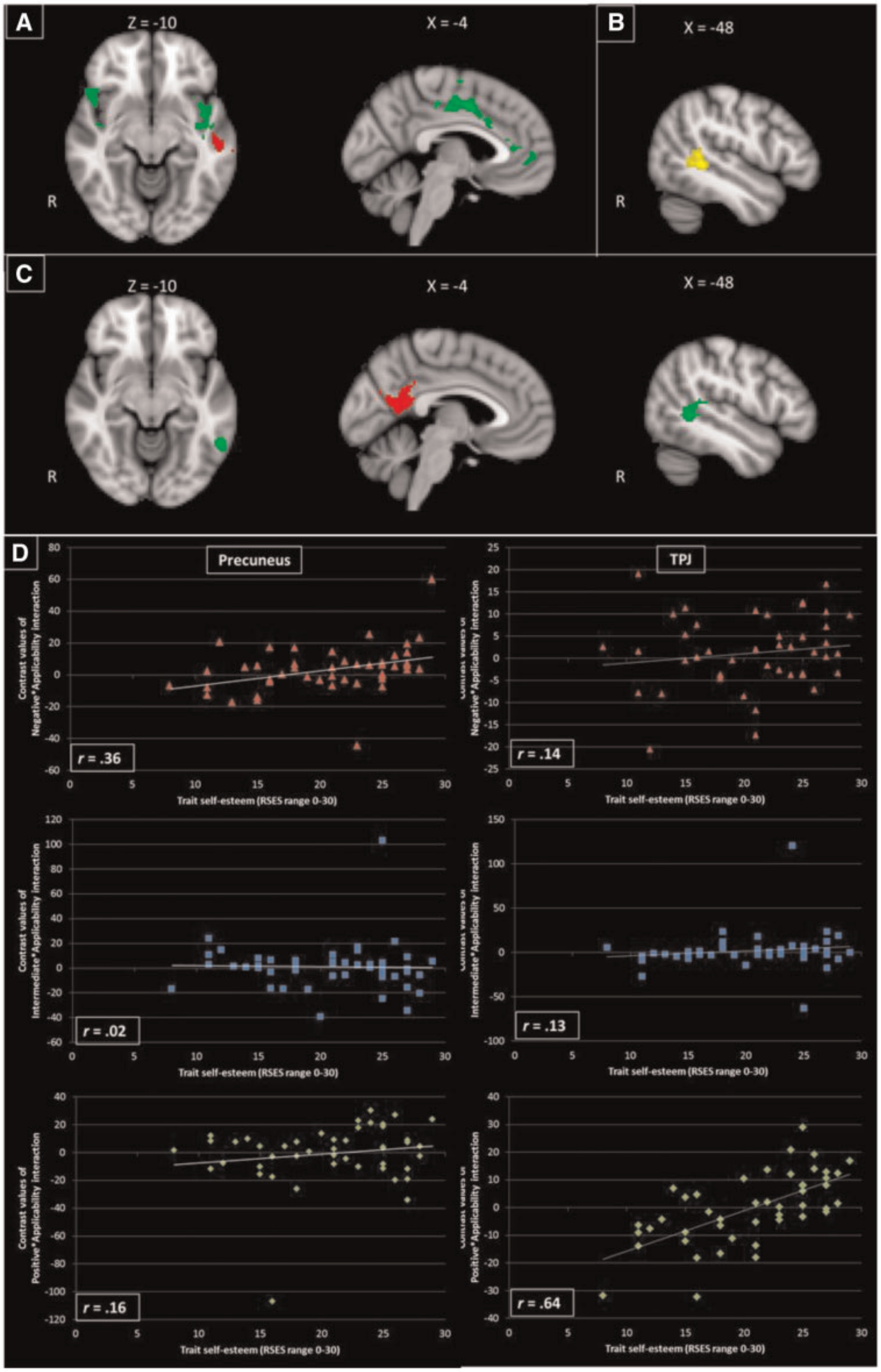

Fig. 4. Neural activation related to trait self-esteem, cluster threshold with z = 2.3 and cluster P <0.05. To facilitate comparability of results, similar coordinates have been used for visualisation. (A) Moderation of trait self-esteem during positive (green) and negative (red) feedback. (B) Moderation of trait self-esteem with applicability of feedback. (C) Interaction effect of trait self-esteem and applicability of feedback during positive (green) and negative (red) feedback. (D) Scatterplot of contrast values in precuneus (left) and TPJ (right) for negative (red triangles), intermediate (blue squares) and positive feedback (green diamonds) for three-way interaction of valence by applicability against level of trait self-esteem.

Negative feedback was more related to the ventral part of the ACC (aMCC) and anterior part of the insula, whereas positive feedback activated the dorsal part of the ACC (pMCC) and posterior part of the insula. Previous studies showed that the more ventral part of the ACC is associated with the encoding of self-relatedness of stimuli and the regulation of negative stimuli, whereas the more dorsal part of the ACC is related to re-appraisal and evaluation of self-related and positive stimuli

Table 5. Neural correlates of trait self-esteem (RSES) in relation to valence and applicability of feedback

Contrast	Cluster size	Cluster *P*-value	Label peak voxels	Voxel test value	MNI coordinates		
				Z	X	Y	Z
RSES×Neg	378	0.027	L Inferior temporal gyrus	3.78	−46	−10	−22
			L MTG, BA20	2.90	−56	−10	−24
RSES×Pos	1528	<.001	R PCC	5.62	10	−18	44
			L ACC, BA24	5.12	−4	0	44
			L Postcentral gyrus, Precuneus	4.38	−14	−40	48
	556	0.002	R IFG	4.01	56	16	−2
			R Insula, OFC, BA13	3.74	34	16	−16
	497	0.004	L Planum polare, BA22	4.06	−50	4	−6
			L Insula	3.68	−42	0	−12
			L MTG	3.39	−48	−8	−20
RSES×Applicability	636	0.001	L Angular gyrus	3.88	−44	−46	8
			L MTG	3.87	−48	−44	2
RSES×Applicability×Neg	744	<0.001	R Precuneus, BA23	3.29	6	−58	16
			L Precuneus, PCC	3.29	−4	−58	14
RSES×Applicability×Pos	324	0.036	L MTG	3.87	−42	−50	4
			L Angular gyrus	3.68	−44	−46	8

Note: All clusters with selected peak voxels, cluster corrected $z = 2.3$, cluster $P < 0.05$.

(Northoff *et al.*, 2006; Mak *et al.*, 2009; Etkin *et al.*, 2011). With respect to the insula, the anterior part seems more important for detecting stimuli and thoughts as self-relevant and facilitating emotional awareness, whereas the posterior part of the insula is related to interoceptive awareness (Craig, 2011; Gu *et al.*, 2013; Simmons *et al.*, 2013). Negative feedback seems more related to becoming aware of and regulating forthcoming emotions whereas positive feedback is more related to reappraising the feedback (Northoff *et al.*, 2006; Etkin *et al.*, 2011; Wiebking and Northoff, 2015). More common neural activation for negative and positive feedback compared to intermediate feedback was found in the PCC and TPJ, relevant for self- and other referential thinking. In sum, negative and positive feedback commonly incite the process of evaluating the relevancy of feedback to the self and the person providing it but may differ in responding to the feedback and resulting emotions. It could be thought that this could be due to negative feedback being more of a threat to the self-concept and social standing (Leary, 2005; vanDellen *et al.*, 2011). However, more research is needed to delineate the specific processes underlying the common and unique neural correlates of negative and positive feedback.

In terms of applicability, feedback that was rated as more applicable was related to a better mood. This relates well to previous findings that confirming existing self-knowledge with consistent feedback is experienced as more pleasurable (Stinson *et al.*, 2010). Moreover, feedback that was rated as more applicable increased neural activation in left precuneus. In the context of self-referential processing, the precuneus is related to using autobiographical memory to place self-relevant stimuli in a temporal context (Cavanna & Trimble, 2006; Northoff *et al.*, 2006). More applicable feedback may result in a better mood through recognising oneself in the feedback.

Trait self-esteem was an important moderator of affective and neural responses to social feedback. Individuals with lower self-esteem felt worse after negative and intermediate feedback compared to individuals with high self-esteem, which is in line with previous findings that high self-esteem acts as a buffer when rejected (Brown, 2010). On the neural level, low self-esteem was related to decreased activation in the left MTG during negative feedback. The MTG is implicated in reflective emotional responding as opposed to a more reactive way of responding (Satpute & Lieberman, 2006; Frewen *et al.*, 2011). Overall, it seems that individuals with lower self-esteem are more affected by negative feedback. As proposed in the introduction, this could be related to a more fragile self-concept (Campbell *et al.*, 1996; Campbell *et al.*, 2003). Individuals with lower self-esteem did report an especially negative mood after negative feedback that was less consistent with their self-knowledge (i.e. less applicable feedback). Moreover, on the neural level, we found that applicability affected the processing of negative feedback more for individuals with higher self-esteem, reflected in more activation in the precuneus and PCC for more applicable negative feedback. In contrast, individuals with low self-esteem did not show these distinct activation patterns, indicating that all negative feedback, regardless of the level of applicability, was processed similarly. It could be that by differentiating negative feedback on level of applicability, individuals with higher self-esteem can process inapplicable negative feedback as not self-relevant and may therefore more easily dismiss it (Cavanna and Trimble, 2006; Northoff *et al.*, 2006). In contrast, individuals with lower self-esteem seem to not filter negative feedback based on applicability and may have more difficulty in dismissing inapplicable negative feedback, which is also reflected in a worse mood.

With respect to positive feedback, individuals with lower self-esteem showed decreased activation in the bilateral mPFC, insula, ACC and PCC. Especially, the mPFC is important for remembering information that is relevant to the self (Kelley *et al.*, 2002; Philippi *et al.*, 2012). This may point to decreased self-referential thinking and self-appraisal for positive feedback when self-esteem is lower (Ochsner *et al.*, 2005; Northoff *et al.*, 2006). Individuals with lower self-esteem also showed decreased activation in the left MTG and posterior TPJ for positive feedback that was more applicable. The TPJ as well as the MTG are part of a large connectivity network in the brain which shares self- and other-referential processing (Lombardo *et al.*, 2010; Molnar-Szakacs and Uddin, 2013). Possibly, when individuals with high self-esteem receive a compliment that matches with their own self-view, this may elicit a positive feeling of mutual understanding and an affective connection with the person providing the feedback. We did find that participants who thought the feedback described them well in general also thought more positively of the confederate and that this relationship was especially strong for people with higher self-esteem. Positive applicable feedback may thus confirm positive aspects of the self-knowledge as well as the social standing with the other person. Interestingly, this process was not observed in individuals with lower self-esteem. Despite rating positive traits as equally relevant for their self-concept, individuals with low self-esteem, may not receive the same 'acceptance signals' from positive feedback (Leary, 2005; Stinson *et al.*, 2010). This result and the three-way interaction with negative feedback, though interesting, requires replication with more participants as it was most affected by confounds, and should therefore be interpreted with caution.

To conclude, individuals with low self-esteem may not only have trouble with processing and filtering negative feedback but also with the integration of positive feedback and feeling connected to the other. Given the fact that our sample included participants with clinically low self-esteem, this may be relevant for patients who suffer from low self-esteem, as for example in as SAD and BPD (Zeigler-Hill & Showers, 2007; Rasmussen and Pidgeon, 2011). Indeed, these patients are more vulnerable to rejection and BPD patients may not integrate positive self-relevant information well (Miano *et al.*, 2013; Winter *et al.*, 2015). It would therefore be interesting to investigate how the self-concept may play a role in dealing with social feedback and how in turn social feedback may play a role in the self-concept formation and maintenance in both SAD and BPD.

A strength of this study is that it not only replicated previous findings with a larger sample, including clinically low self-esteem participants, but also added to the existing literature by simultaneously and thoroughly studying the role of valence, applicability and trait self-esteem on affective and neural responses to dealing with social feedback. Moreover, we used statistical analyses i.e. multi-level analysis and parametric modulation that were on trial basis which allowed for the analysis of the idiosyncrasy of the feedback to each individual. Furthermore, the experimental paradigm proved very credible and the positive and negative feedback induced clear affective and neural responses. Finally, both affective and neural responses were integrated, as has been promoted in the field (Eisenberger, 2015).

A limitation of this study is that applicability of feedback words was measured after participants received the feedback and may therefore be influenced by the feedback. The paradigm did not allow for rating the feedback words before participants were supposedly evaluated by these words. However, participants were explicitly instructed to rate how they thought these words applied to them regardless of what the confederate thought. Still, a replication of these findings where applicability ratings are measured before evaluation is encouraged. Moreover, we investigated females only and the results may therefore not be generalizable to males as other studies have shown that gender influences the responses to and coping with social feedback (Stroud *et al.*, 2002; Matud, 2004; Benenson *et al.*, 2013). Finally, it was not possible to statistically control for the motor confound induced by left and right-hand button presses. Given meta-analytic findings on finger tapping, we assume the motor confound is restricted to the sensorimotor cortex and cerebellum areas (Witt *et al.*, 2008). Moreover, our confidence in the neural findings is supported by similar findings in meta-analyses on self-referential thinking, rejection and theory of mind and our behavourial findings. However, future studies should counter balance hand use.

Conclusion

Information received from others is important to construct and validate the self-concept (Swann and Brooks, 2012) as well as to inform us about our social standing (Leary, 2005). We showed that specific self-views, i.e. consistency of self-knowledge with feedback and global self-esteem, play an important role when responding to social feedback. Individuals with low self-esteem seem to process and filter negative feedback less effectively and may perceive the relevance of positive feedback for their self-concept and social standing less well. These new insights may enhance our understanding of individuals with clinically low levels of self-esteem and their difficulties navigating the social world.

Supplementary data

Supplementary data are available at *SCAN* online.

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