



Citation for published version:

Hobbs, C, Sui, J, Kessler, D, Munafò, MR & Button, KS 2023, 'Self-processing in relation to emotion and reward processing in depression', *Psychological Medicine*, vol. 53, no. 5, pp. 1924 - 1936.
<https://doi.org/10.1017/S0033291721003597>

DOI:

[10.1017/S0033291721003597](https://doi.org/10.1017/S0033291721003597)

Publication date:

2023

Document Version

Peer reviewed version

[Link to publication](#)

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1 **Title**

2 Self processing in relation to emotion and reward processing in depression

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11 NHS Foundation Trust and the University of Bristol

12 **Declarations**

13 Funding: This study was funded by a GW4 BioMed MRC Doctoral Training Partnership award to
14 Catherine Hobbs.

15 Acknowledgements: We would like to thank the participants who took part in this study.

16 Conflicts of Interest: None.

17 Author Contribution: CH and KSB conceptualised the study aims and design. JS and KSB provided
18 materials for the study, and CH created the remaining materials. All authors obtained funding for the
19 study. JS, DK, MRM and KSB provided supervisory support. CH recruited participants and collected
20 data. CH cleaned, analysed and archived the data. CH wrote the original draft of this manuscript,
21 which was reviewed and edited by JS, DK, MRM and KSB.

22 Ethical Declaration: The authors assert that all procedures contributing to this work comply with the
23 ethical standards of the relevant national and institutional committees on human experimentation
24 and with the Helsinki Declaration of 1975, as revised in 2008. All procedures involving human
25 subjects were approved by the University of Bath Department of Psychology Ethics Committee (18-
26 167). Written informed consent was obtained from all participants.

27 Data Availability: The data that support the findings of this study are openly available in the
28 University of Bath Research Data Archive (<https://doi.org/10.15125/BATH-00924>).

29

30 **Abstract Word Count: 238 / 250**

31 **Text Word Count: 6232 / 4500**

32 **Abstract**

33 Background: Depression is characterised by a heightened self-focus, which is believed to be
34 associated with differences in emotion and reward processing. However, the precise relationship
35 between these cognitive domains is not well understood. We examined the role of self-reference in
36 emotion and reward processing, separately and in combination, in relation to depression.

37 Methods: Adults experiencing varying levels of depression ($n = 144$) completed self-report
38 depression measures (PHQ-9, BDI-II). We measured self, emotion, and reward processing, separately
39 and in combination, using three cognitive tasks.

40 Results: When self processing was measured independently of emotion and reward, in a simple
41 associative learning task, there was little association with depression. However, when self and
42 emotion processing occurred in combination in a self-esteem go/no-go task, depression was
43 associated with an increased positive other bias ($b = 3.51$, 95% CI: 1.24, 5.79). When the self was
44 processed in relation to emotion and reward, in a social evaluation learning task, depression was
45 associated with reduced positive self biases ($b = 0.11$, 95% CI: 0.05, 0.17).

46 Conclusions: Depression was associated with enhanced positive implicit associations with others,
47 and reduced positive learning about the self, culminating in reduced self-favouring biases. However,
48 when self, emotion and reward processing occurred independently there was little evidence of an
49 association with depression. Treatments targeting reduced positive self-biases may provide more
50 sensitive targets for therapeutic intervention and potential biomarkers of treatment responses,
51 allowing the development of more effective interventions.

52 **Introduction**

53 Depression is a highly prevalent mental health problem worldwide (World Health Organization,
54 2017), and is projected to be the leading cause of disease burden globally by 2030 (World Health
55 Organization, 2011). Treatments for depression are moderately effective (Cipriani et al., 2018;
56 Cuijpers, Andersson, Donker, & Van Straten, 2011), but individual response varies (Maslej, Furukawa,
57 Cipriani, Andrews, & Mulsant, 2020). Understanding the cognitive processes maintaining depression
58 may allow us to develop sensitive targets for therapeutic intervention. In this study we explored the
59 role of self processing in depression, in relation to emotion and reward processing.

60 *Self Processing*

61 Across the general population, people show greater attention, recall and learning of self-related
62 stimuli, often referred to as the self-prioritisation effect (Cunningham & Turk, 2017; Sui, He, &
63 Humphreys, 2012; Sui & Humphreys, 2015a). However, individuals experiencing depression exhibit a
64 heightened focus on the self, and difficulty disengaging from an internal self-referential focus
65 (Northoff, 2007; Sheline et al., 2009). Paradoxically, this heightened internal self-referential focus
66 may prevent individuals from associating novel stimuli with internal representations of the self (Sui,
67 Ohrling, & Humphreys, 2016). This concept has previously been demonstrated in a study where
68 following a negative mood induction participants were worse at associating arbitrarily assigned
69 neutral shapes with the self (Sui et al., 2016). Individuals experiencing depression may subsequently
70 be limited in their ability to update their self-concept from environmental feedback, perpetuating
71 maladaptive views of the self.

72 The strength and consistency of self-prioritisation effects has led to proposals of the self being an
73 integrative hub through which incoming stimuli is processed (Sui & Humphreys, 2015a). Targeting
74 abnormalities in self-referential processing in depression may have wider implications for other
75 cognitive domains implicated in depression. This is likely to include emotion (Ma & Han, 2010) and
76 reward (Northoff & Hayes, 2011), as they are fundamental behavioural drivers and neurally overlap
77 in the medial prefrontal cortex.

78 *Self and Emotional Processing*

79 Negative perceptions of the self are believed to play a causal role in the development of depression.
80 According to Beck's cognitive theory, individuals experiencing depression develop negative views of
81 the self as an internalised reaction to repeated adverse social experiences. When activated by
82 stressful life events these negative self-schema dominate information processing, promoting
83 automatic processing of negative information about the self (Beck, 2008). Supportive of this theory,

84 emotional biases are more likely to be observed in depression when stimuli is processed in reference
85 to the self (Gaddy & Ingram, 2014; Hertel & El-Messidi, 2006; Ji, Grafton, & MacLeod, 2017). Altering
86 negative information processing in relation to the self is therefore a key target for therapeutic
87 interventions for depression.

88 *Self and Reward Processing*

89 Depression is also associated with a hyposensitivity to reward and hypersensitivity to punishment
90 (Eshel & Roiser, 2010). There is evidence to suggest that this is linked to self processing. Self-relevant
91 information induces activity in areas of the brain also activated during reward processing, such as
92 the ventral medial prefrontal cortex, ventral striatum and ventral tegmental area (Northoff & Hayes,
93 2011). Differences in self-processing in depression may be at least partially driven differences in
94 reward processing. In keeping with this theory, individuals with greater depression were found to
95 continue to selectively engage in negative thoughts about the self even when this resulted in
96 economic loss (Takano, Van Grieken, & Raes, 2019). Targeting reward processing in depression may
97 have wider effects on self processing and vice versa.

98 *Self, Emotion and Reward Processing*

99 The interaction between self, emotion and reward processing may be a key combination of cognitive
100 processes maintaining depression. Patients with depression show reduced activation of both reward
101 and self-related areas of the brain when processing positive stimuli (Northoff, 2007; Northoff &
102 Hayes, 2011). Reduced self-referential processing of positive information has also been identified as
103 the most robust predictor of low approach motivation and reward responsivity (Hsu et al., 2020).
104 Increased sensitivity to punishing feedback may sustain preferential processing of negative
105 information about the self, reinforcing negative self-schema. Likewise, reduced sensitivity to positive
106 feedback may reduce the ability to learn positive information about the self. The intersection
107 between self, emotion and reward may therefore be the most effective target for cognitive
108 treatments for depression.

109 *Aims and Hypotheses*

110 We explored the role of the self in relation to emotion and reward processing associated with
111 varying levels of depressive symptoms. In contrast to previous studies that focused on either of
112 these independent cognitive process (based on self, reward, or emotion) or interactions between
113 any two components, we used three cognitive tasks to examine relationships between these
114 processes and depressive symptoms, not only as distinct cognitive processes but also how they
115 functionally interact.

116 To examine self, reward and emotion processing occurring independently we used associative
117 learning tasks where participants paired neutral shapes with self-relevant, emotionally valenced, and
118 varying degrees of reward, in three separate tasks. Based on previous research (Sui et al., 2016), we
119 predicted that increased depression severity would be associated with worse performance when
120 associating shapes with the self. Similarly based on evidence of impaired affective processing in
121 depression (Daggleish & Watts, 1990; Dalili, Penton-Voak, Harmer, & Munafò, 2015; Eshel & Roiser,
122 2010), we predicted that depression would be associated with worse performance when associating
123 shapes with positive and rewarding stimuli.

124 To examine self, reward and emotion processing occurring in interaction we used a social
125 reinforcement learning task where participants learnt when the computer liked themselves and
126 others. Based on previous evidence (Hobbs et al., 2019), we hypothesised that increasing depression
127 severity would be associated with worse learning of the self being 'liked'.

128 We also included a self-esteem go/no-go task due to its ability to integrate self and emotion
129 processing. Participants rapidly categorised emotional and referential words, with greater
130 discriminative accuracy believed to reflect existing implicit associations. An implicit negative self-
131 esteem would therefore be reflected by greater discriminative accuracy when categorising self-
132 referential and negative stimuli. However, due to mixed findings regarding the role of response
133 inhibition in depression (Lewis, Button, Pearson, Munafò, & Lewis, 2020), and no previous use of this
134 task within our research group we made no hypotheses regarding this task.

135

136 **Methods**

137 This study was pre-registered on the Open Science Framework (<https://osf.io/34ma2>), where study
138 materials are also available. Study data are available in the University of Bath Research Data Archive
139 (<https://doi.org/10.15125/BATH-00924> ; Hobbs, Sui, Kessler, Munafò, & Button, 2020).

140 ***Participants***

141 We recruited participants aged 18 to 65, fluent in English, with normal or corrected-to-normal vision,
142 through campus advertising at the University of Bath. As depression severity is positively skewed
143 (Tomitaka, Kawasaki, & Furukawa, 2015), to ensure balanced levels of depression we screened
144 participants using the Patient Health Questionnaire (PHQ-9; Kroenke, Spitzer, & Williams, 2001). We
145 recruited an equal number of participants with no depression (PHQ-9 < 5), mild depression (PHQ-9
146 5-9) and moderate to severe depression (PHQ-9 ≥ 10).

147 ***Procedure***

148 Participants completed two testing sessions, on average eight days apart (SD 3). At each session
149 participants completed a social evaluation learning task, allowing measurement of test-retest
150 reliability. To reduce fatigue effects associated with reaction time tasks, participants completed a
151 go/no-go task at session one and an associative learning task at session two. At each session
152 participants completed self-report measures of mood after the cognitive tasks.

153 ***Materials***

154 **Cognitive Tasks**

155 To personalise tasks, prior to testing participants provided the first names of themselves, a friend,
156 and a stranger.

157 ***Associative Learning Task***

158 We used three simple associative learning tasks to measure how self, emotion and reward
159 processing are independently associated with depression (Stolte, Humphreys, Yankouskaya, & Sui,
160 2017; Sui & Humphreys, 2015b). In each task, participants learnt to associate stimuli related to the
161 relevant area of processing (e.g. Self: names of the self, a friend and a stranger; Emotion: happy,
162 neutral and sad faces; Reward: £9, £3, £1), with abstract shapes. These tasks were completed
163 sequentially in a counterbalanced order.

164 At the start of each task participants were instructed to learn randomly-assigned stimuli-shape
165 pairings. Two blocks of 60 trials were completed per task. In each trial a fixation point was displayed

166 for 200 ms, followed by a stimuli-shape pairing presented for 100 ms (self, reward) or 150 ms
167 (valence task only due to greater visual stimuli complexity). Participants pressed the 'n' or 'm' keys
168 to indicate whether the presented pairings matched with the learnt association (Figure 1a). Key
169 assignment to 'matching' or 'non-matching' responses was randomised for each participant but
170 consistent across tasks. A response limit of 1100 ms was applied. Feedback was presented for each
171 trial for 500 ms ("correct" / "incorrect" / "too slow"). At the end of each block participants were
172 informed of their accuracy. For the reward task only, participants received a monetary reward based
173 on the proportion of correct trials per reward stimuli.

174 Accuracy and reaction times (ms) were recorded. Prioritisation of stimuli is indicated by faster
175 reaction times and/or higher accuracy.

176 *Self-Esteem Go/No-Go Task*

177 To measure how self and emotion processing occurring in interaction are associated with
178 depression, we used a self-esteem go/no-go task. This task is proposed to measure implicit self-
179 esteem (Gregg & Sedikides, 2010).

180 Participants were asked to categorise characteristics as positive (e.g. 'charming', 'smart') or negative
181 (e.g. 'cruel', 'boring'), and referential worlds as related to the self, specified to participants as 'me'
182 (e.g. participants' first name, 'me', 'I'), or others, specified to participants as 'not-me' (e.g. 'they',
183 'them', 'others'). In the training phase participants categorised words according to single categories
184 (e.g. positive, negative, me, not-me), with 20 trials per condition. In the test phase, participants
185 categorised words belonging to paired categories (e.g. positive OR me, positive OR not-me, negative
186 OR me, negative OR not-me). There were 16 practice trials and 48 test trials for each paired
187 combination of categories. An equal number of trials for stimuli relating to each condition was
188 presented per block. A response timeout of 600 ms was applied. Block order was randomised.

189 At the beginning of each block the condition(s) by which words should be categorised was presented
190 at the top of the screen and remained in place throughout the block. In each trial a word belonging
191 to any of the conditions (e.g. positive, negative, me or not-me) was presented at the centre of the
192 screen for 600 ms. Participants were asked to press the spacebar if the presented word related to
193 the specified category (a 'go' response) or to refrain from pressing the spacebar if the word did not
194 relate to the specified category (a 'no-go' response) (Figure 1b).

195 We categorised responses in test trials according to hits (a 'go' response when the stimuli belonged
196 to the specified categories) and false alarms (a 'go' response when the stimuli did not belong to the
197 specified categories). Responses to both referential and valence stimuli were included. For example,

198 if the specified categories were 'positive OR me' a trial was considered a hit if a 'go' response was
199 given upon presentation of a positive characteristic *or* a self-referential word.

200 Discriminative accuracy (d') for each referential-emotion block was calculated by applying z-score
201 transformations and subtracting hits from false alarms. Greater d' values indicate greater accuracy,
202 suggesting stronger associations between paired-categories.

203 *Social Evaluation Learning Task*

204 To measure self, emotion and reward learning occurring simultaneously we used a reinforcement
205 learning task within a social context (Button, Karwowska, Kounali, Munafò, & Attwood, 2016;
206 Button, Browning, Munafò, & Lewis, 2012; Button et al., 2015). Participants learnt how much the
207 computer 'liked' the self, a friend and a stranger based on feedback to a forced choice selection
208 between positive and negative social evaluation pairings (Figure 1c). A response time limit was not
209 imposed. Participants learnt two rules based on the probability of the positive evaluations being
210 'correct' ('Like' 60-80%, 'Dislike' 20-40%). The number of errors made before reaching the criterion
211 of eight consecutive rule-congruent responses were recorded. Bias scores were calculated by
212 subtracting errors to criterion made when learning the dislike rule from the like rule. A positive value
213 indicates a negative bias, as fewer errors were made learning the dislike rule compared to the like
214 rule. We also calculated participants cumulative accuracy across trials in each condition-rule block to
215 visualise learning curves.

216 After completing each rule block participants were also asked to provide a global rating of how much
217 the computer liked the person, ranging from 'Complete Dislike' (0) to 'Complete Like' (10).

218 Participants completed all referential-conditions and rules. Order of referential-condition, and
219 nested within this rule, was randomised. All participants completed 24 trials per referential-
220 condition rule block.

221 [Figure 1 here]

222 Self-Report Measures

223 We measured depression severity using the Patient Health Questionnaire (PHQ-9) (Kroenke et al.,
224 2001) and Beck Depression Inventory (BDI-II) (Beck, Steer, & Brown, 1996). The PHQ-9 and BDI-II are
225 self-administered questionnaires of the experience of depression within the previous two weeks.
226 The PHQ-9 consists of nine items relating to the DSM-IV diagnostic criteria with scores ranging from
227 0-27, whereas the BDI-II consists of 21 items with scores ranging from 0-63 and has a greater focus
228 on cognitive symptoms. Both measures demonstrate good psychometric properties (Cameron,

229 Crawford, Lawton, & Reid, 2008; Wang & Gorenstein, 2013), and are widely used in clinical practice
230 (Kendrick et al., 2009).

231 We also identified whether participants met ICD-10 criteria for a primary diagnosis of a Major
232 Depressive Episode (MDE) using the Clinical Interview Schedule-Revised (CIS-R; Lewis, Pelosi, Araya,
233 & Dunn, 1992). The CIS-R is a fully structured self-administered computerised assessment that
234 provides ICD-10 diagnoses of common mental health disorders. It has previously been used in large
235 scale epidemiological studies within the general population.

236 As social anxiety has previously been associated with performance on the Social Evaluation Learning
237 task (Button et al., 2015), we also measured social anxiety using the Brief Fear of Negative
238 Evaluation Scale (Leary, 1983). To characterise the clinical profile of our sample we collected
239 additional self-report measures of mental health and cognition. We measured anxiety using the
240 Generalised Anxiety Disorder Scale (GAD-7; Spitzer, Kroenke, Williams, & Löwe, 2006), anxiety
241 relating to positive social feedback using the Fear of Positive Evaluation Scale (Weeks, Heimberg, &
242 Rodebaugh, 2008), self-esteem using the Rosenberg Self-Esteem Scale (RSES; Rosenberg, 1965), and
243 self-schema using the Dysfunctional Attitude Scale (DAS; Weissman & Beck, 1978). Finally, we
244 measured change in state mood before and after completion of the cognitive tasks using the Positive
245 and Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988).

246 ***Statistical Analyses***

247 *Sample Size Calculation*

248 A priori power calculations indicated that 144 participants would be required to provide greater than
249 80% power at an alpha level of 0.05 to detect previously observed effect sizes ($\eta^2 = 0.05$) for the
250 relationship between bias scores in the self condition in the Social Evaluation Learning task and
251 depression severity (Button et al., 2016, 2012, 2015; Hobbs et al., 2019), and greater than 99%
252 power to detect previously observed effect sizes for the relationship between reaction times when
253 matching shapes with the 'self' on the Associative Learning Task and depression severity ($\eta^2 = 0.17$)
254 (Sui & Button, 2017).

255 *Data Exclusion*

256 Data was excluded according to a priori criteria as specified in our pre-registration.

257 For the associative learning task, trials with reaction times less than 200 ms (0.8%) and trials with no
258 response (8%) were excluded. We included matching and non-matching trials in our analyses. For
259 reaction time data we used both correct and incorrect responses.

260 We excluded 36 (25%) participants from the Go/No-Go Self-Esteem analyses due to a pattern of
261 response indicating non-compliance (discrimination scores lower than 5 and/or bias scores less than
262 12 or greater than 36). As the exclusion rate was high, we repeated the main analyses for this task
263 with all participants included as a sensitivity analysis.

264 Due to a technical error, data for the social evaluation learning task was unavailable in the second
265 session for one participant.

266 *Statistical Models*

267 All analyses were conducted in R 3.6.

268 To aid interpretation we have provided both standardised (β) and unstandardised (b) regression
269 coefficients.

270 We first assessed whether task performance differed across conditions using mixed-effects linear
271 regression models. Separate models were used for each task, and for each measure of performance.
272 Subject was entered as a random effect to account for within-subject effects. Task performance
273 measures were entered as the outcome, and conditions as predictors.

274 Whilst the associative learning task and go/no-go task have previously been evidenced to have
275 acceptable levels of reliability (Stolte, Humphreys, Yankouskaya, & Sui, 2016; Williams & Kaufmann,
276 2012), the reliability of the social evaluation learning task is yet to be tested. We calculated
277 intraclass correlation coefficients for bias scores in the social evaluation learning task, using two-way
278 mixed-effects models to calculate absolute agreement and consistency as recommended for
279 cognitive-behavioural measures (Parsons, Kruijt, & Fox, 2019).

280 We used linear regression models to assess the relationship between task performance and
281 depression. In all models, task outcomes were entered as separate predictors according to condition
282 (e.g. in the self associative learning task accuracy model, accuracy in the self, friend and stranger
283 condition were entered as separate predictors). We used depression as the outcome in these
284 models, rather than a predictor as is typical in psychiatric experimental models, in preparation for
285 future work using the cognitive task outcomes as predictors of change in depression severity.
286 Separate models were conducted for each task outcome with PHQ-9 or BDI-II scores used as
287 continuous outcomes. As the social evaluation learning task was completed in two sessions, we used
288 mixed-effects linear regression models with session included as an additional predictor and subject
289 as a random effect.

290 To examine the reliability of our findings for individuals meeting diagnostic criteria for depression,
291 we repeated the primary analyses for each task using logistic regression models. Primary diagnosis
292 of major depressive episode derived from the CIS-R was used as a binary outcome (diagnostic
293 criteria met/not met). As the CIS-R was only completed at session 1, for tasks with multiple
294 timepoints data from session 1 was used.

295 Full details of models are provided in the supplementary materials.

296

297 **Results**

298 ***Participant Characteristics***

299 We recruited 144 participants, all of whom provided data for analysis. To demonstrate variability
300 across depression severity, participant characteristics grouped according to PHQ-9 clinical cut-offs
301 are presented in Table 1. The PHQ-9 and BDI-II showed excellent test-retest reliability between
302 sessions (PHQ-9: ICC 0.94 (95% CI 0.89, 0.96), BDI-II: ICC: 0.96 (95% CI: 0.94, 0.97)), and strongly
303 correlated ($r = 0.90$, 95% CI: 0.88, 0.92).

304 [Table 1 here]

305 ***Associative Learning Task***

306 **Hypothesis:** Depression will be associated with reduced learning of self, highly rewarding and
307 positive stimuli as indicated by reduced accuracy and greater reaction times.

308 *Self*

309 Consistent with prior evidence of self-prioritisation (Sui et al., 2012), participants on average showed
310 the highest level of accuracy and fastest reaction times when matching shapes with the name of the
311 self versus a friend or stranger (Supplementary Tables S1 and S2). We found no evidence to support
312 our hypothesis; ability to associate shapes with the self, a friend or a stranger was not associated
313 with depression (Table 2).

314 *Reward*

315 Likewise consistent with previous evidence of prioritisation of higher levels of reward (Sui &
316 Humphreys, 2015b), participants on average were more accurate and faster when matching shapes
317 with the highest level of reward (Supplementary Tables S1 and S2).

318 We found some evidence that increased accuracy when matching shapes with the medium level of
319 reward was associated with greater depression. For every 1% increase in accuracy when matching
320 shapes with '£3', PHQ-9 and BDI-II scores increased by 0.10 (b 95% CI: 0.02, 0.19, $p = 0.021$) and 0.24
321 (b 95% CI: 0.05, 0.43, $p = 0.012$) points respectively.

322 There was also weak evidence that decreasing accuracy when matching shapes with the high level of
323 reward was associated with increased BDI-II scores ($b = -0.19$, b 95% CI: -0.37, 0.00, $p = 0.051$).

324 However, confidence intervals overlapped with the null and there was little evidence of a similar
325 relationship for PHQ-9 scores. We therefore found only weak support for our hypothesis.

326 No association was observed between accuracy when matching shapes with the low level of reward
327 (£1) and depression severity (Table 2). We also found no relationship between reaction times and
328 depression for this task (Table 2).

329 *Emotion*

330 Consistent with previous evidence of prioritisation of positive stimuli (Stolte et al., 2017),
331 participants on average were more accurate and faster at matching shapes with happy faces
332 (Supplementary Tables S1 and S2). However, in contrast with our hypothesis, accuracy or reaction
333 times were not associated with depression (Table 2).

334 [Table 2 here]

335 ***Self-Esteem Go/No-Go Task***

336 Due to previous mixed findings for the role of response inhibition in depression we made no
337 hypothesis regarding this task, our findings should therefore be considered exploratory.

338 We found strong evidence of an interaction between referential condition and emotion on
339 discriminative accuracy in the self-esteem Go/No-Go Task ($b = 0.79$, b 95% CI: 0.61, 0.97, $\beta = 1.31$, β
340 95% CI: 1.01, 1.61, $p < .001$; Supplementary Table S3). On average, participants showed a positive
341 bias towards the self with greater discriminative accuracy for positive (M 1.40, SD 0.56) versus
342 negative (M 1.0, SD 0.52) associations with the self. The opposite pattern was observed when
343 associating words with the other (positive: M 0.71, SD 0.48, negative: M 1.12, SD 0.62).

344 We found consistent evidence that discriminative accuracy in the 'other' condition was associated
345 with depression severity. Increased discriminative accuracy when associating positive words with
346 others was associated with greater depression severity using both the PHQ-9 ($b = 3.51$, b 95% CI:
347 1.24, 5.79, $\beta = 0.30$, β 95% CI: 1.24, 5.79, $p = 0.003$) and BDI-II ($b = 6.78$, b 95% CI: 1.93, 11.64, $\beta =$
348 0.28, β 95% CI: 0.08, 0.47, $p = 0.007$). Conversely, increased discriminative accuracy when
349 associating negative words with others was associated with lower PHQ-9 ($b = -2.46$, b 95% CI: -4.24, -
350 0.68, $\beta = -0.27$, β 95% CI: -0.46, -0.07, $p = 0.007$), and BDI-II scores ($b = -5.13$, b 95% CI: -8.92, -1.34,
351 $\beta = -0.27$, β 95% CI: -0.46, -0.07, $p = 0.008$). Individuals with greater depression therefore showed
352 both a greater positive bias, and a reduced negative bias, when processing information about others.

353 Evidence for an association between discriminative accuracy in the self condition and depression
354 was less consistent. Increased discriminative accuracy when associating positive words with the self
355 was associated with a decrease in PHQ-9 scores ($b = -2.47$, b 95% CI: -4.54, -0.39, $\beta = -0.24$, β 95% CI:
356 -0.44, -0.04, $p = 0.020$). Although an effect in the same direction was observed for BDI-II scores,

357 confidence intervals overlapped substantially with the null ($b = -3.20$, b 95% CI: -7.62, 1.23, $\beta = -0.15$,
358 β 95% CI: -0.36, 0.06, $p = 0.155$). There was little evidence of an association between discriminative
359 accuracy when associating negative words with the self with either the PHQ-9 ($b = -0.59$, b 95% CI: -
360 2.57, 1.39, $\beta = -0.05$, β 95% CI: -0.24, 0.13, $p = 0.553$) or BDI-II ($b = 0.81$, b 95% CI: -5.03, 3.41, $\beta = -$
361 0.04, β 95% CI: -0.22, 0.15, $p = 0.704$).

362 As we excluded a large proportion of participants (25%) in these analyses due to a priori criteria
363 indicating non-compliance with the task, we repeated these analyses including all participants as a
364 sensitivity analysis. We no longer found evidence for an association between discriminative accuracy
365 in the other-negative condition and PHQ-9 severity, as confidence intervals overlapped with the null.
366 However, the results described above persisted for all other associations (Supplementary Table S4).

367 ***Social Evaluation Learning***

368 **Hypothesis:** Depression will be associated with reduced positive biases when learning about the self,
369 driven by a greater number of errors before learning the positive 'like' rule.

370 *Bias Scores*

371 Participants on average were most positively biased when learning about the friend, making 2.07
372 fewer errors learning positive relative to negative evaluations (b 95% CI: -2.93, -1.21, $\beta = -0.35$, β
373 95% CI: -0.49, -0.20, $p < .001$), compared to when learning about the self. Participants displayed
374 similar levels of bias when learning about the self and stranger ($b = -0.44$, b 95% CI: -1.31, 0.42, $\beta = -$
375 0.07, β 95% CI: -0.22, 0.07, $p = 0.318$). The estimated agreement and consistency for bias scores
376 across test sessions was ICC = 0.41 (95% CI: 0.29, 0.52).

377 In support of our hypothesis, bias scores when learning about the self were associated with
378 depression severity. For every additional error learning the positive relative to the negative rule,
379 PHQ-9 scores increased by 0.11 points (b 95% CI: 0.05, 0.17, $p < .001$) and BDI-II scores increased by
380 0.23 points (b 95% CI: 0.12, 0.34, $p < .001$). Effects were specific to learning about the self; bias
381 scores when learning about the friend or a stranger were not associated with depression (Figure 2a;
382 Table 3).

383 We also conducted additional exploratory analyses to examine whether the relationship between
384 self bias scores and depression symptoms was consistent across sessions. We found little evidence
385 of an interaction suggesting that the relationship did not vary over the two sessions (PHQ-9 $b = 0.04$,
386 b 95% CI: -0.04, 0.11, $\beta = 0.02$, β 95% CI: -0.02, 0.06, $p = 0.377$; BDI-II $b = 0.07$, b 95% CI: -0.07, 0.21,
387 $\beta = 0.02$, β 95% CI = -0.02, 0.06, $p = 0.315$).

388 [Figure 2 here]

389 *Errors to Criterion*

390 To investigate whether the relationship between bias scores and depression severity was driven by
391 worse learning of the positive rule, or better learning of the negative rule, we examined the
392 relationship between errors to criterion in each referential-rule condition and depression.

393 Participants overall were positively biased, making greater errors learning the negative versus
394 positive rules ($b = 1.45$, b 95% CI: 0.82, 2.07, $p < .001$; Supplementary Table S5) The greater bias
395 scores in the friend condition, as outlined above, was driven by participants making both fewer
396 errors learning the positive rule (M 5.39, SD 3.76) and greater errors learning the negative rule (M
397 8.90, SD 4.24), compared to the self (positive M 6.50, SD 4.22; negative M 7.95 SD 4.28) and stranger
398 (positive M 6.34 SD 3.90, negative M 8.23 SD 3.97) conditions.

399 We found consistent evidence to support our hypothesis that depression would be associated with a
400 greater number of errors when learning the self-positive rule. For every additional error before
401 learning the self-positive rule, PHQ-9 scores increased by 0.17 points (b 95% CI: 0.08, 0.26, $p < .001$)
402 and BDI-II scores increased by 0.31 points (b 95% CI: 0.15, 0.47, $p < .001$).

403 We also found weak evidence that worse learning of the friend being disliked was associated with
404 greater PHQ-9 scores, and better learning of the self being disliked was associated with reduced BDI-
405 II scores (Table 3). However, confidence intervals were relatively wide, and these effects were not
406 observed in the alternative depression measure for each, suggesting unreliable effects.

407 Errors to criterion when learning that a friend was liked, or either rule about the stranger, were not
408 associated with PHQ-9 or BDI-II scores (Table 3).

409 *Cumulative Accuracy*

410 Figure 2b demonstrates the cumulative mean accuracy over the 24 learning trials for the positive
411 'like' and negative 'dislike' rules about the self in participants grouped according to none, mild, and
412 moderate to severe levels of depression on the PHQ-9 and BDI-II. In keeping with our findings for
413 errors to criterion, participants with moderate to severe levels of depression demonstrated impaired
414 learning of the self-like rule as indicated by lower levels of mean accuracy both initially and
415 cumulatively across trials.

416 *Global Ratings*

417 After each rule we asked participants to provide a global rating of how much the computer 'liked'
418 the person.

419 Demonstrating understanding of each rule, participants gave lower global ratings following
420 completion of the negative versus positive rules ($b = -2.67$, 95% CI: -2.85, -2.49, $p < .001$).

421 Additionally, participants showed slightly increased perceptions of the friend being liked compared
422 to the self ($b = 0.32$, 95% CI: 0.14, 0.50, $p = 0.001$), but gave similar global ratings in the self and
423 stranger conditions ($b = 0.09$, 95% CI: -0.10, 0.27, $p = 0.354$). Full results are available in
424 supplementary Table S5.

425 Consistent with our findings for errors to criterion, increased perceptions of being liked after
426 completing the self-positive rule were associated with lower depression severity (Table 3). We also
427 found weak evidence that greater global ratings in the stranger-positive condition was associated
428 with greater PHQ-9 scores, however there was little evidence of this association with BDI-II scores
429 (Table 3).

430 *Social Anxiety*

431 The effects outlined above persisted when social anxiety was taken into account, suggesting an
432 independent relationship between social evaluation learning and depression (Supplementary Table
433 S6).

434

435 [Table 3 here]

436 ***Reliability of findings with clinical diagnosis of depression***

437 To examine whether our findings were valid for participants meeting clinical diagnostic criteria for
438 depression, we repeated the primary analyses for each task using logistic regression models with
439 primary diagnosis of major depressive episode, derived from the CIS-R, as a binary outcome. The
440 primary effects of each task were replicated; increased positive biases towards others in the self-
441 esteem go/no-go task and reduced positive biases towards the self in the social evaluation learning
442 task, were associated with an increased odds of meeting diagnostic criteria for a major depressive
443 episode. Full details are available in supplementary materials (Supplementary Tables S7-S9).

444 ***Adjusting for Age and Gender***

445 The results of our primary analyses were consistent when we adjusted for age and gender
446 (Supplementary Table S10).

447 **Discussion**

448 Depression is characterised by differences in processing self-related information, which are believed
449 to be related to emotion and reward cognition. However, the precise relationship between these
450 areas of processing is not yet well understood. In this study we examined the role of the self in
451 emotion and reward processing, separately and in interaction, in individuals experiencing varying
452 levels of depression. Healthy individuals typically show enhanced positive perceptions of the self,
453 relative to others (De Jong, 2002). We found that when the self was processed in relation to emotion
454 and reward, this self-favouring bias was reduced in individuals with greater depression severity.
455 However, when self, emotion and reward processing occurred independently there was little
456 evidence of an association with depression.

457 Using a social evaluation learning task, we found evidence of interaction between self, emotion, and
458 reward processing with depression. During social interactions, healthy individuals preferentially
459 incorporate positive evaluations into their self-concept (Korn, Prehn, Park, Walter, & Heekeren,
460 2012). In support of our pre-registered hypothesis, we found that participants with greater
461 depression showed a reduced positive self-bias when learning social evaluations. Participants with
462 greater depression made a greater number of errors before learning that they were 'liked' and gave
463 lower global ratings of being liked. Depression was therefore consistently associated with a reduced
464 ability to learn positive, socially rewarding information about the self.

465 Using a go/no-go task, we found that individuals with greater depression severity showed increased
466 sensitivity to positive words in relation to others, and decreased sensitivity to negative words.
467 However, in keeping with previous research using response inhibition tasks we found only weak
468 evidence of an association between implicit self-esteem and depression (De Jong, Sportel, De Hullu,
469 & Nauta, 2012; Franck, De Raedt, & De Houwer, 2008; Van Tuijl, De Jong, Sportel, De Hullu, & Nauta,
470 2014). Depression was therefore characterised by increased positive 'other-esteem', but not by an
471 increased negative self-esteem. Our research adds to evidence suggesting that individuals with
472 depression tend to perceive others more positively (Kuiper, Derry, & MacDonald, 1982). Depression
473 has previously been theorised to originate from discrepancies between internal self-representations,
474 and representations of the ideal self (Higgins, 1987). Enhanced positive perceptions of others may
475 increase discrepancies between views of the actual and idealised self, perpetuating depressive
476 symptoms. Alternatively, our findings of a weak association between implicit self-esteem and
477 depression may reflect debate over the construct validity of implicit association tests (Hahn, Judd,
478 Hirsh, & Blair, 2014), or questions over the extent to which affective response inhibition are
479 associated with depression severity (Lewis et al., 2020).

480 When the self was processed independently of emotion or reward, within an associative learning
481 task, we did not find evidence of changes in self-prioritisation with greater depression severity. This
482 contrasts with previous findings of reduced self-prioritisation following negative mood induction (Sui
483 et al., 2016). Whilst temporary, sudden changes in state mood may inhibit self-prioritisation in the
484 absence of emotional processing, this does not seem to apply to low trait mood. We also found no
485 evidence that depression was associated with differences in learning emotional associations when
486 processed independently of the self. There were some indications of differences in reward learning
487 associated with depression. Although, in contrast to our expectations this was only observed for
488 medium levels of reward. It is possible that depression alters sensitivity to reward, with greater
489 value being placed on lower levels of reward. However, confidence intervals were relatively wide for
490 this effect. Further research replicating these results is therefore required in order to understand
491 their importance.

492 A substantial body of research suggests that healthy individuals hold relatively enhanced perceptions
493 of the self versus others (Kuiper et al., 1982), and typically rate their abilities as better-than-average
494 (Zell, Strickhouser, Sedikides, & Alicke, 2019). These positive self-biases are believed to be beneficial
495 for mental health in increasing self-esteem and confidence (Button et al., 2015). Our results indicate
496 that when processed independently of emotion, at least at a 'cold' perceptual level as in the
497 associative learning task, self-referential processing is similar irrespective of depression severity.
498 However, differences were observed when integrating positive and negative information with the
499 self and others. Overall, depression was characterised by a reduction in self-favouring biases.
500 Individuals with greater depression showed both greater implicit positive perceptions of others, and
501 impaired learning of positive associations with the self. Depression may be driven by other-favouring
502 biases strengthened by reduced learning of positive information about the self. In combination,
503 reduced positive perceptions of the self and enhanced positive perceptions of others are likely to
504 maintain negative views of the self.

505 *Clinical Implications*

506 Acknowledging that much of the work in therapy already implies self-reference, our findings suggest
507 that it may be beneficial to explicitly manipulate referential focus and target biases in emotion and
508 reward processing in relation to the self. Social evaluation learning in particular may be an important
509 target for intervention. Depression is associated with poorer quality social interactions (Teo, Choi, &
510 Valenstein, 2013), and social withdrawal (Hirschfeld et al., 2000). Our findings suggest that
511 individuals with depression show a stable pattern of reduced learning of positive evaluations about
512 the self. Reduced positive self-biases in social interactions are likely to maintain negative perceptions

513 of the self, reinforcing social withdrawal and increasing the likelihood of poor social relationships,
514 subsequently maintaining depression symptoms (Lewinsohn, Mischel, Chaplin, & Barton, 1980).
515 Social evaluation learning provides an important and potentially reversible target for therapeutic
516 intervention that can address impairments in social functioning, negative perceptions of the self, and
517 wider depressive symptoms. It is also possible that social evaluation learning may be a
518 transdiagnostic mechanism. Future research examining latent mental health traits would allow us to
519 understand the importance of social evaluation learning across mental health disorders.

520 Additionally, we found evidence that the relationship between biased learning about the self and
521 depression was consistent across testing sessions. Change in social evaluation learning may
522 therefore be a viable predictor of change in depressive symptoms. Individual treatment response for
523 depression is varied (Maslej et al., 2020). It is currently difficult to predict which treatments are
524 effective at an individual level (Simon & Perlis, 2010). Exacerbating these difficulties are the long
525 time periods between commencing treatment and improvement in mood (Uher et al., 2011).
526 Identifying markers of therapeutic change would be beneficial in allowing identification of effective
527 treatments at an earlier timepoint. Further research examining changes in learning positive
528 evaluations about the self as a potential predictor of treatment response would be beneficial.

529 *Limitations*

530 We recruited participants based on depression severity to gain a balanced range of depression.
531 However, in the time between screening and testing, depression severity on average decreased
532 potentially weakening our effects. In-depth analysis of larger samples representative of the
533 spectrum of individuals with depression would be fruitful to further characterise changes in self-
534 referential processing and to replicate the current findings. Although, our results were replicated for
535 individuals meeting diagnostic criteria for depression, suggesting that our results are reliable for
536 greater severities of depression.

537 Additionally, whilst our sample was representative of the range of depressive symptoms
538 experienced in the general population it was limited in its demographic diversity. Participants were
539 predominantly young, students and female. While this may be an ideal sample to investigate the role
540 of self biases in depression, given the worrying increase of depression in this population at a
541 developmentally sensitive time where self-identity and peer relations are evolving (Blakemore &
542 Mills, 2014; Royal College of Psychiatrists, 2011), future studies should investigate whether these
543 findings generalise across the wider population and test whether the strength of the associations
544 alter across adulthood.

545 Whilst we found evidence of a consistent relationship between biased learning about the self and
546 depression in the social evaluation learning task, bias scores themselves showed limited reliability
547 between test sessions. Further development of this task to improve reliability would be beneficial.

548 Finally, this was a cross-sectional study examining the association between self, emotion and reward
549 processing with depression. We are therefore unable to comment on the causal role of self
550 processing in relation to emotion and reward. Future research examining the longitudinal
551 relationship between self processing and depression would provide insight into the potential causal
552 role of reduced positive self-biases. Additionally, manipulating self-referential affective processing
553 through cognitive bias modification would help us understand the importance of this cognitive style
554 in maintaining depression symptoms.

555 *Conclusion*

556 Overall, our findings suggest that depression is characterised by enhanced positive implicit
557 associations with others, and reduced positive learning about the self, culminating in reduced self-
558 favouring biases observed in healthy individuals. We also found some evidence of altered sensitivity
559 to reward in individuals with greater depression severity using a simple associative learning task,
560 although this effect requires further replication. Treatments targeting reduced positive self-biases
561 may provide more sensitive targets for therapeutic intervention and potential biomarkers of
562 treatment responses, allowing the development of more effective interventions.

563

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753

754

755 Table 1

756 *Participant Characteristics according to Depression Severity*

	PHQ-9 Depression Severity		
	None (<5)	Mild (5-9)	Moderate to Severe (≥10)
N (%)	48 (33)	56 (39)	40 (28)
Age, M (SD)	23.4 (7.3)	22.6 (7.9)	20.9 (3.1)
Gender, N (%)			
Male	11 (23)	11 (19)	9 (22)
Female	37 (77)	44 (79)	31 (78)
Other	0 (0)	1 (2)	0 (0)
Ethnicity, N (%)			
White	33 (69)	30 (54)	33 (85)
Black	0 (0)	2 (4)	1 (3)
Asian	11 (23)	18 (32)	3 (7)
Mixed	4 (8)	4 (7)	2 (5)
Other	0 (0)	2 (3)	0 (0)
Employment, N (%)			
Student	42 (88)	50 (89)	36 (90)
Employed	5 (10)	6 (11)	3 (8)
Other	1 (2)	0 (0)	1 (2)
CIS-R Primary Diagnosis Major Depressive Episode, N (%)	0 (0)	9 (16)	26 (65) ^a
Current Treatment, N (%)			
Psychological Therapy	0 (0)	3 (5)	5 (13)
Antidepressants	0 (0)	2 (4)	7 (18)
PHQ-9, M (SD)	2.5 (1.2)	6.9 (1.4)	15.0 (4.0)
BDI-II, M (SD)	4.6 (3.6)	13.1 (5.6)	27.2 (10.5)
BFNE, M (SD)	34.3 (10.2)	38.8 (9.1)	45.9 (8.2)
GAD-7, M (SD)	2.1 (2.1)	5.4 (3.0)	10.9 (4.1)
FPE, M (SD)	23.2 (11.1)	26.8 (13.5)	36.5 (14.2)
DAS-24, M (SD)	90.3 (17.8)	94.9 (18.5)	108.3 (15.5)

RSES, M (SD)	13.6 (1.9)	12.9 (2.5)	12.7 (2.1)
PANAS Positive Change, M (SD)	-1.5 (3.2)	-1.9 (3.3)	-1.9 (4.2)
PANAS Negative Change, M (SD)	-0.7 (2.1)	-0.7 (2.2)	-1.1 (4.0)

757 ^a Participants who met criteria for a primary diagnosis of a MDE within this group had higher PHQ-9 (M 16.21, SD 4.35) and
758 BDI-II scores (M 31.88, SD 10.42), compared to those that did not have a primary diagnosis of a MDE (PHQ-9: M 12.00, SD
759 1.83, BDI-II: 19.57, SD 5.95).

760 CIS-R = Clinical Interview Schedule Revised, PHQ-9 = Patient Health Questionnaire, BDI-II = Beck Depression Inventory,
761 BFNE = Brief Fear of Negative Evaluation, GAD-7 = Generalised Anxiety Questionnaire, BFNE = Brief Fear of Negative
762 Evaluation Scale, FPE = Fear of Positive Evaluation Scale, DAS-24 = Dysfunctional Attitudes Scale, RSES = Rosenberg Self-
763 Esteem Scale, PANAS = Positive and Negative Affect Schedule.

764 Note: All data presented in this table were collected at the first testing session. PANAS change scores reflect differences in
765 scores from pre- to post-completion of the cognitive tasks.

766 Table 2

767 Results from linear regression models examining the association between accuracy and reaction times for each task condition (predictors) in the associative
 768 learning task with depression (Outcome: PHQ-9/BDI-II)

Task	Stimuli	PHQ-9					BDI-II				
		<i>b</i>	<i>b</i> 95% CI	β	β 95% CI	<i>p</i>	<i>b</i>	<i>b</i> 95% CI	β	β 95% CI	<i>p</i>
Accuracy (%)											
Self	Intercept	11.44	3.38, 19.49	0.00	-0.16, 0.16	0.006	14.51	-2.78, 31.79	0.00	-0.17, 0.17	0.099
	Self	-0.06	-0.17, 0.05	-0.12	-0.33, 0.10	0.288	-0.15	-0.39, 0.10	-0.13	-0.35, 0.08	0.231
	Friend	-0.04	-0.15, 0.06	-0.09	-0.32, 0.13	0.414	0.03	-0.20, 0.26	0.03	-0.20, 0.26	0.790
	Stranger	0.05	-0.04, 0.15	0.13	-0.10, 0.36	0.279	0.11	-0.09, 0.32	0.13	-0.10, 0.36	0.275
Reward	Intercept	6.07	1.08, 11.06	0.00	-0.16, 0.16	0.018	8.59	-2.02, 19.20	0.00	-0.16, 0.16	0.112
	High (£9)	-0.06	-0.15, 0.03	-0.18	-0.43, 0.07	0.166	-0.19	-0.37, 0.00	-0.25	-0.50, 0.00	0.051
	Medium (£3)	0.10	0.02, 0.19	0.30	0.05, 0.56	0.021	0.24	0.05, 0.43	0.33	-0.07, 0.58	0.012
	Low (£1)	-0.03	-0.10, 0.04	-0.10	-0.31, 0.11	0.366	0.02	-0.13, 0.16	0.02	-0.18, 0.23	0.814
Emotion	Intercept	6.05	1.05, 11.04	0.00	-0.17, 0.17	0.018	10.72	0.05, 21.39	0.00	-0.17, 0.17	0.049
	Happy	-0.02	-0.09, 0.05	-0.06	-0.27, 0.15	0.588	-0.05	-0.21, 0.11	-0.06	-0.28, 0.15	0.547
	Neutral	0.03	-0.05, 0.11	0.08	-0.15, 0.32	0.498	0.06	-0.11, 0.23	0.08	-0.15, 0.32	0.489
	Sad	0.01	-0.07, 0.08	0.02	-0.22, 0.25	0.881	0.04	-0.13, 0.20	0.05	-0.18, 0.28	0.668
Reaction Times (ms)											
Self	Intercept	11.50	2.64, 20.37	0.00	-0.17, 0.17	0.011	24.45	5.50, 43.40	0.00	-0.16, 0.16	0.012
	Self	0.00	-0.02, 0.03	0.05	-0.27, 0.37	0.755	0.00	-0.05, 0.06	0.01	-0.31, 0.34	0.929

	Friend	-0.01	-0.04, 0.01	-0.20	-0.60, 0.19	0.317	-0.04	-0.09, 0.02	-0.24	-0.64, 0.15	0.277
	Stranger	0.00	-0.03, 0.03	0.04	-0.39, 0.48	0.846	0.02	-0.05, 0.08	0.11	-0.32, 0.55	0.610
Reward	Intercept	4.53	-2.38, 11.44	0.00	-0.17, 0.17	0.197	7.89	-6.88, 22.65	0.00	-0.17, 0.17	0.293
	High (£9)	0.01	-0.01, 0.04	0.22	-0.15, 0.59	0.245	0.03	-0.01, 0.08	0.26	-0.11, 0.63	0.168
	Medium (£3)	-0.01	-0.04, 0.02	-0.19	-0.65, 0.27	0.422	-0.01	-0.07, 0.04	-0.09	-0.55, 0.36	0.685
	Low (£1)	0.00	-0.02, 0.02	0.02	-0.36, 0.40	0.933	-0.01	-0.06, 0.03	-0.11	-0.49, 0.26	0.549
Emotion	Intercept	7.51	1.64, 13.37	0.00	-0.17, 0.17	0.013	14.33	1.75, 26.91	0.00	-0.17, 0.17	0.026
	Happy	0.01	-0.01, 0.02	0.10	-0.28, 0.48	0.614	0.00	-0.04, 0.04	0.02	-0.36, 0.41	0.898
	Neutral	0.00	-0.03, 0.02	-0.06	-0.55, 0.44	0.824	0.00	-0.05, 0.05	0.00	-0.49, 0.50	0.990
	Sad	0.00	-0.03, 0.02	-0.07	-0.57, 0.44	0.793	0.00	-0.05, 0.04	-0.04	-0.55, 0.46	0.867

769 b = unstandardised regression coefficients, β = standardised regression coefficients

770

771 Table 3

772 *Results from mixed-effect linear regression models examining the relationship between social evaluation learning task outcomes (predictors) and depression*
 773 *(Outcome: PHQ-9/BDI-II)*

	PHQ-9					BDI-II				
	<i>b</i>	<i>b</i> 95% CI	β	95% CI	<i>p</i>	<i>b</i>	<i>b</i> 95% CI	β	95% CI	<i>p</i>
Bias Scores										
Intercept	8.54	7.47, 9.60	0.00	-0.15, 0.15	< .001	15.18	13.06, 17.30	0.00	-0.16, 0.15	< .001
Self	0.11	0.05, 0.17	0.13	0.06, 0.20	< .001	0.23	0.12, 0.34	0.13	0.07, 0.19	< .001
Friend	-0.03	-0.09, 0.03	-0.04	-0.11, 0.01	0.259	0.01	-0.10, 0.11	0.00	-0.05, 0.06	0.898
Stranger	-0.01	-0.08, 0.05	-0.01	-0.08, 0.05	0.731	0.00	-0.12, 0.11	0.00	-0.06, 0.05	0.943
Session	-0.88	-1.29, -0.46	-0.08	-0.12, -0.04	< .001	-0.73	-1.47, 0.02	-0.03	-0.06, 0.00	0.057
Errors to Criterion										
Intercept	7.45	5.91, 8.99	0.00	-0.15, 0.15	< .001	13.79	10.84, 16.73	0.00	-0.15, 0.15	< .001
Self-Positive	0.17	0.08, 0.26	0.13	0.06, 0.20	< .001	0.31	0.15, 0.47	0.12	0.06, 0.18	< .001
Self-Negative	-0.05	-0.13, 0.04	-0.04	-0.10, 0.03	0.264	-0.17	-0.32, -0.02	-0.06	-0.12, -0.01	0.031
Friend-Positive	0.03	-0.05, 0.16	0.02	-0.04, 0.08	0.492	0.01	-0.14, 0.16	0.00	-0.05, 0.05	0.916
Friend-Negative	0.08	0.05, 0.16	0.06	0.00, 0.12	0.038	-0.01	-0.15, 0.13	0.00	-0.06, 0.05	0.867
Stranger-Positive	-0.05	-0.13, 0.04	-0.03	-0.09, 0.03	0.294	0.02	-0.14, 0.17	0.01	-0.05, 0.06	0.840
Stranger-Negative	-0.03	-0.12, 0.06	-0.02	-0.09, 0.04	0.475	0.04	-0.13, 0.20	0.01	-0.04, 0.07	0.659
Session	-0.87	-1.29, -0.45	-0.08	-0.12, -0.04	< .001	-0.73	-1.49, 0.03	-0.03	-0.07, 0.00	0.062
Global Ratings										

Intercept	9.24	6.45, 12.02	0.00	-0.16, 0.16	< .001	17.77	12.48, 23.06	0.00	-0.16, 0.15	<.001
Self-Positive	-0.52	-0.82, -0.22	-0.12	-0.19, -0.05	0.001	-0.73	-1.29, -0.17	-0.08	-0.14, -0.02	0.012
Self-Negative	0.13	-0.17, 0.44	0.03	-0.04, 0.10	0.398	0.03	-0.54, 0.60	0.00	-0.06, 0.07	0.925
Friend-Positive	-0.04	-0.35, 0.28	-0.01	-0.07, 0.06	0.806	0.08	-0.51, 0.67	0.01	-0.05, 0.07	0.796
Friend-Negative	0.23	-0.04, 0.51	0.05	-0.01, 0.12	0.094	0.34	-0.16, 0.85	0.04	-0.02, 0.09	0.186
Stranger-Positive	0.32	0.03, 0.62	0.07	0.01, 0.14	0.033	-0.17	-0.72, 0.39	-0.02	-0.08, 0.04	0.554
Stranger-Negative	-0.16	-0.45, 0.13	-0.04	-0.10, 0.03	0.272	0.20	-0.34, 0.74	0.02	-0.04, 0.08	0.465
Session	-0.91	-1.33, -0.49	-0.08	-0.12, -0.04	< .001	-0.78	-1.57, 0.00	-0.03	-0.07, 0.00	0.052

774

b = unstandardised regression coefficients, β = standardised regression coefficients

775 *Figure 1*

776 Cognitive Task Procedures

777 (a) Associative Learning Tasks: Example of an introduction, trial and feedback for each type for
778 each type of task (self, reward, emotion). In the introduction of each task participants were
779 instructed to associate specified randomly-assigned shape and stimuli pairings. In each trial
780 participants were presented with a random combination of these shape-stimuli pairings and
781 were asked to use the 'n' and 'm' keys to indicate whether these matched with the pairings
782 they had previously learnt. In these examples, the 'm' key indicates a 'matching' responses
783 and the 'n' key indicates a 'non-matching' response, however key assignment was
784 randomised for each participant. Following each trial, feedback was given indicating if the
785 participant was correct, incorrect, or too slow (> 1100 ms). Each of these examples
786 demonstrate a 'matching' trial, where the presented shape-stimuli match with the pairings
787 specified in the introduction. A 'matching' response would therefore be correct, in this
788 example the 'm' key, whereas an 'non-matching' response would be incorrect, in this
789 example the 'n' key.

790 (b) Go/No-Go Self-Esteem Association Task: Example of a trial and feedback for the Self-Positive
791 condition. The conditions that words should be categorised according to (in this instance Me
792 or Nice) were presented at the top of the screen throughout the block. In each trial a word
793 was presented at the centre of the screen. Participants were asked to press the spacebar if
794 the word belonged to a specified category (a 'go' response) or to refrain from pressing the
795 spacebar if the word did not belong to the specified category (a 'no-go' response). Feedback
796 (correct indicated by a green circle, or incorrect indicated by a red cross) was given for each
797 response. In this example, a 'no-go' response would be considered a correct rejection and a
798 'go' response would be considered a false alarm, as the stimuli ('those') does not belong to
799 the Me or Positive categories.

800 (c) Social Evaluation Learning Task: Example of a trial and feedback. Participants were asked to
801 select the word that they felt reflected the computers' opinion of the person being learnt
802 about (self, friend or stranger), and were given feedback on their response. The proportion of
803 trials deemed correct upon selection of the positive word was manipulated to reflect learning
804 of two different rules: positive 'like' 60-80%, negative 'dislike' 20-40%.

805 *Figure 2*

806 (a) Relationship between bias scores in the self, friend and stranger conditions in the social
807 evaluation learning task with (i) PHQ-9 and (ii) BDI-II scores.

808 (b) Learning curves in the self condition in the social evaluation learning task based on
809 cumulative accuracy with depression severity grouped according to (i) PHQ-9 clinical cut-offs
810 and (ii) BDI-II clinical cut-offs.

811