

Major depression impairs incentive processing: evidence from the heart and the face

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Original Article

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Cite this article: Franzen J, Brinkmann K, Gendolla GHE, Sentissi O (2019). Major depression impairs incentive processing: evidence from the heart and the face. *Psychological Medicine* **49**, 922–930. <https://doi.org/10.1017/S0033291718001526>

Received: 15 February 2018
Revised: 4 May 2018
Accepted: 15 May 2018
First published online: 18 June 2018

Key words:

Depression; effort mobilization; facial expressions; incentive anticipation; incentive consumption; punishment; reward

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Abstract

Background. The present study tested the hypothesis of a differential pattern of reward and punishment responsiveness in depression measuring effort mobilization during anticipation and facial expressions during consumption.

Methods. Twenty patients with major depressive disorder (MDD) and 20 control participants worked on a memory task under neutral, reward, and punishment instructions. Effort mobilization was operationalized as cardiovascular reactivity, while facial expressions were measured by facial electromyographic reactivity. Self-report measures for each phase complemented this multi-method approach.

Results. During anticipation, MDD patients showed weaker cardiac pre-ejection period (PEP) reactivity to reward and blunted self-reported wanting, but weaker PEP reactivity to punishment and unchanged self-reported avoidance motivation. During consumption, MDD patients showed reduced zygomaticus major muscle reactivity to reward and blunted self-reported liking, but unchanged corrugator supercilii muscle reactivity to punishment and unchanged self-reported disliking.

Conclusions. These findings demonstrate reduced effort mobilization during reward and punishment anticipation in depression. Moreover, they show reduced facial expressions during reward consumption and unchanged facial expressions during punishment consumption in depression.

Introduction

Patients with major depressive disorder (MDD) often suffer from impairments in reward and punishment processing (see Eshel and Roiser, 2010; Pizzagalli, 2014, for reviews). Reward processing is comprised of two parts. First, its anticipatory component – or *wanting* – corresponds to the motivation to obtain a reward. Second, its consummatory component – or *liking* – is defined as the affective responses to reward (Berridge and Robinson, 2003; Gard *et al.*, 2006; Berridge and Kringelbach, 2008). Similarly, punishment processing can be divided into anticipatory and consummatory components (Franzen and Brinkmann, 2016b).

Concerning the *anticipatory component of reward processing* in depression, reduced approach behavior and reduced subjective motivation to obtain rewards might lead to reduced responsiveness during reward anticipation (Beck *et al.*, 1979; Depue and Iacono, 1989; Fowles, 1994; Jacobson *et al.*, 2001) – as indicated by behavioral, neuroimaging, and self-report studies (e.g. Forbes *et al.*, 2009; Olino *et al.*, 2011; Smoski *et al.*, 2011; Shankman *et al.*, 2013). Regarding the *anticipatory component of punishment processing* in depression, empirical results are inconsistent (Eshel and Roiser, 2010). Some studies have found reduced punishment responsiveness (Gotlib *et al.*, 2010; Schiller *et al.*, 2013); others have not (Knutson *et al.*, 2008; Olino *et al.*, 2011). On the theoretical level, avoidance behavior in depression is well documented (Ottenbreit and Dobson, 2004; Trew, 2011). Presumably, avoidance behavior is associated with a preserved subjective motivation to avoid punishments in both depressed and non-depressed individuals. Furthermore, depression is characterized by disengagement (Rottenberg *et al.*, 2005) and hopelessness (Abramson *et al.*, 1978), underlining the passive nature of avoidance behavior in depression. The subjective motivation to avoid punishments seems to translate into effective active avoidance in non-depressed individuals, but into ineffective passive avoidance in the depressed.

To date, only a few studies have investigated the effort depressed individuals mobilize when anticipating positive or negative outcomes (Brinkmann *et al.*, 2009; Brinkmann and Franzen, 2013; Brinkmann *et al.*, 2014; Franzen and Brinkmann, 2015, 2016a; Brinkmann and Franzen, 2017). Effort mobilization is defined as the mobilization of resources in order to attain goals (Gendolla and Wright, 2009) and refers to the intensity of motivation. According to motivational intensity theory (Brehm and Self, 1989), rewards and punishments directly influence success importance and, by this way, effort mobilization when task difficulty is unspecified

and a performance standard is unknown to the individual (termed *unclear task difficulty*) (Brehm and Self, 1989; Richter, 2012). In other words, the bigger the reward or the punishment at stake, the more important is success and, therefore, the greater is effort mobilization when task difficulty is unclear.

Effort mobilization can reliably be quantified as beta-adrenergic impact of the sympathetic nervous system on the heart in the context of active coping with an instrumental task (Wright, 1996) and thus especially as the reactivity of cardiac pre-ejection period (PEP) – the time interval between the onset of left ventricular excitation and the opening of the heart's aortic valve (Levick, 2003). Systolic blood pressure (SBP), which is systematically influenced by myocardial contraction force, can also mirror effort. Diastolic blood pressure (DBP), which is predominantly determined by total peripheral resistance and, therefore, by alpha-adrenergic sympathetic activation, and (HR), which is determined by both sympathetic and parasympathetic activation, are more ambiguous as effort indices (Papillo and Shapiro, 1990). Several studies with healthy participants have demonstrated increased cardiovascular reactivity during performance on rewarded, unclear-difficulty tasks in comparison with a neutral condition (Richter and Gendolla, 2006, 2007, 2009). In contrast, subclinically depressed individuals show reduced cardiovascular reactivity when performing rewarded or punished tasks (Brinkmann *et al.*, 2009; Brinkmann and Franzen, 2013; Brinkmann *et al.*, 2014; Franzen and Brinkmann, 2015, 2016a; Brinkmann and Franzen, 2017). However, only two subclinical studies (Franzen and Brinkmann, 2016b) have simultaneously investigated the anticipatory and the consummatory components of reward and punishment processing. A complete picture of the entire process of reward and punishment responsiveness on a peripheral physiological level in MDD is still lacking.

Theories and empirical studies focusing on the *consummatory component of incentive processing* are less extensive than those regarding the anticipatory component. While self-report, behavioral, and neuroimaging studies consistently show reduced responses during reward consumption in depressed individuals (Forbes *et al.*, 2009; Dichter *et al.*, 2012; Foti *et al.*, 2014; Weinberg and Shankman, 2017), reports of depression effects during punishment consumption are inconsistent or not reliable (Pizzagalli *et al.*, 2009a; Sherdell *et al.*, 2012; Schiller *et al.*, 2013).

Past research on the consummatory component of incentive processing has mainly relied on self-report and neuroscientific measures. Little attention has been given to affective facial expressions. Facial electromyography (EMG) is an objective and subtle measure of affective reactions to the receipt of rewards and punishments (Berridge and Robinson, 2003). EMG activity over the corrugator supercilii muscle region can reflect negative affective experiences, while EMG activity over the zygomaticus major muscle region can mirror positive affect (Cacioppo *et al.*, 1986). Some studies found impaired zygomaticus major muscle activity in response to positive stimuli in depressed individuals, whereas depressed and non-depressed individuals showed comparable increases in corrugator supercilii muscle activity to negative stimuli (Schwartz *et al.*, 1976; Sloan *et al.*, 2001; Sloan *et al.*, 2002). Recently, two studies found lower zygomaticus major activity during reward receipt in subclinically depressed individuals, while their corrugator supercilii activity during punishment was similar to that of non-depressed individuals (Franzen and Brinkmann, 2016b). However, evidence for this differential response pattern in MDD is still lacking.

To close this gap, we investigated reward and punishment responsiveness in a clinical sample of MDD patients compared

with a non-depressed control group. Effort-related cardiovascular reactivity assessed the anticipatory reward and punishment responsiveness during the performance of an instrumental task (i.e. wanting). Facial EMG reactivity assessed the affective responses to reward and punishment consumption (i.e. liking). These objective measures were accompanied by self-report measures of participants' motivation to seek reward and to avoid punishment and the pleasure or displeasure of reward or punishment consumption.

In line with our *a priori* hypotheses, we recorded physiological activity only during the respective periods of interest, namely, cardiovascular activity during anticipation, zygomaticus major activity during reward consumption, and corrugator supercilii activity during punishment consumption. All procedures were approved by the Central Ethics Committee of the University Hospitals of Geneva in accordance with the provision of the World Medical Association Declaration of Helsinki.

Our hypotheses were as follows. (A) Reward anticipation: Based on the assumption of reduced approach behavior in depression (Fowles, 1994) and supporting empirical findings (Franzen and Brinkmann, 2016b; Brinkmann and Franzen, 2017), we expected reduced cardiovascular reactivity and self-reported wanting in MDD. (B) Punishment anticipation: Reflecting avoidance motivation in depression (Ottenbreit and Dobson, 2004), we predicted similar self-reported motivation to avoid the punishment for MDD and control participants. However, we expected reduced cardiovascular reactivity in MDD (Franzen and Brinkmann, 2015), because of MDD patients' passive avoidance (Abramson *et al.*, 1978). (C) Reward consumption: Mirroring reduced positive affect in depression (Clark and Watson, 1991) and empirical results (Sloan *et al.*, 2002; Franzen and Brinkmann, 2016b), we predicted reduced zygomaticus major muscle reactivity and reduced self-reported liking in MDD. (D) Punishment consumption: Reflecting negative affect in depression (Clark and Watson, 1991), we hypothesized that corrugator supercilii muscle reactivity and self-reported disliking would be similar in MDD and control participants (Sloan *et al.*, 2002; Franzen and Brinkmann, 2016b).

Methods and materials

Participants

We aimed at collecting valid data of 21 participants per condition, based on an *a priori* power analysis (G*Power 3.1; Faul *et al.*, 2007) referring to a previous subclinical study's results (Franzen and Brinkmann, 2016b). Finally, we could include valid data of 20 individuals with MDD (10 women, 10 men) and 20 healthy controls (10 women, 10 men) with no history of psychiatric disorder. Participants were 19–74 years old ($M = 42.65$, $s.d. = 13.69$) (more information about inclusion/exclusion criteria, demographic characteristics, and medication appears in the online Supplementary material).

Procedure

The protocol consisted of a screening session and an experimental session. Both were individually conducted by the same clinically trained experimenter and took about 60 min each. During the screening, all participants answered demographical and clinical questions and responded to the clinical questions of the Mini International Neuropsychiatric Interview (MINI; Sheehan *et al.*, 1997).

The experimental session was conducted using a personal computer and experimental software (Inquisit 3.0, Millisecond Software, Seattle, WA) that presented all stimuli and instructions. It was divided into a neutral, a reward, and a punishment part. Participants first performed the neutral part and subsequently the two incentive parts in counterbalanced order. During the neutral part, participants watched an 8-min excerpt of a hedonically neutral documentary movie for cardiovascular baseline measures. Afterward, the experimenter explained the upcoming memory task, which took 2.8 min during which we assessed cardiovascular activity. The reward and punishment parts started with similar habituation periods. Then, the experimenter explained the specific contingencies (i.e. reward or punishment), and participants rated their motivation to obtain the reward or to avoid the punishment (i.e. subjective wanting). Afterward, participants worked on new trials of the same 2.8-min memory task. After each task, participants were informed about the performance standard, their own performance score, and received the reward or the punishment message. During this fixed period of 10 s, affective responses to reward or punishment were assessed via facial EMG. Finally, participants evaluated the affective value of the incentive (i.e. liking).

Experimental task and incentive manipulation

We used a modified Sternberg short-term memory task (Sternberg, 1966), composed of 14 trials (more information appears in the online Supplementary material). In the reward part, participants learned that they could win 10 Swiss Francs (about 10 USD) if their performance met or exceeded a performance standard to be revealed later. In the punishment part, participants received a credit of 10 Swiss Francs that they stood to lose if they did not meet the success criterion to be revealed later. Unbeknownst to participants, the performance standards were individually adjusted so that all participants got the reward or lost their credit. To sustain the manipulation, the experimenter placed the money in front of the participants (reward part) or handed out the credit before starting the task (punishment part).

Physiological measures

A Cardioscreen® 2000 hemodynamic monitoring-system (medis, Ilmenau, Germany) (see Scherhag *et al.*, 2005, for a validation study) continuously sampled (1000 Hz) electrocardiogram (ECG) and impedance cardiogram (ICG) signals to determine cardiac PEP [in milliseconds (ms)] and HR [in beats per minute (bpm)]. Four dual gel-pad sensors (medis-ZTECT™) were placed on each side of the base of participants' neck and on each side of the thorax at the level of the xiphoid. The same system measured SBP [in millimeters of mercury (mmHg)] and DBP [in millimeters of mercury (mmHg)] oscillometrically. A blood pressure cuff placed over the brachial artery above the elbow of participants' non-dominant arm automatically inflated every minute.

A MindWare monitor (MindWare Technologies LTD, Gahanna, OH) continuously recorded (1000 Hz) facial EMG signals [in microvolts (μV)] starting 2 s before and ending 10 s after participants learned that they had gained or lost the money. This system uses 5 Ag/AgCl surface electrodes (diameter 4-mm) filled with specific conductive gel for bipolar recording. Electrode placement followed the guidelines by Fridlund and Cacioppo (1986). The first electrode assessing zygomaticus major muscle activity was positioned in the middle of an imaginary line extending from the corner of the lip at rest (i.e. cheilion) to the corner of

the ear (i.e. ipsilateral condylion). Continuing along this imaginary line, the second electrode was placed approximately 1 cm further back. The first electrode assessing corrugator supercilii muscle activity was positioned just superior to the eyebrow along an imaginary vertical line that traverses the inner commissure of the eye fissure (i.e. endocanthion). The second one was placed laterally to the first, approximately 1 cm from the eyebrow's edge. The reference electrode was attached to the forehead on the edge of the hairline. The EMG signal was filtered (10–500 Hz) to maximize the signal-to-noise ratio (Tassinary *et al.*, 2007) and amplified with a constant gain of 1000 (Fridlund and Cacioppo, 1986).

Self-report measures

Subjective motivation and affective responses were assessed with single-item measures using visual analog scales. To assess the severity of depressive symptomatology, the French version of the Montgomery Asberg Depression Rating Scale (Bouvard and Cottraux, 2010) was used for screening purposes. In order to confirm any current or past Axis I disorder according to the international classification of diseases (ICD-10; World Health Organization, 2011), the French version of the MINI was assessed by the experimenter, a clinical psychologist with extensive training for this specific interview (more information about the self-report instruments appears in the online Supplementary material).

Data reduction and analysis

For PEP assessment, the first derivative of the change in thoracic impedance was computed. The resulting dZ/dt signal was synchronized with the ECG signal and ensemble averaged over 60-s periods. HR (in beats/min) and ECG R-onset were automatically detected by LabVIEW (National Instruments, Austin, TX)-based software (Richter, 2014) and visually confirmed. The ICG B-point (indicating the aortic valve's opening) was visually determined by two independent raters (Sherwood *et al.*, 1990). PEP was determined as the time interval between ECG R-onset and ICG B-point (Berntson *et al.*, 2004). Because the inter-rater agreement was high [$ICC_{(2,1)} = 0.98$; Shrout and Fleiss, 1979], we used the arithmetic mean of both raters' PEP values for statistical analyses.

PEP, HR, SBP, and DBP baseline scores (Cronbach's $\alpha > 0.98$) were computed as the arithmetic means of the last 4 min of each habituation period. Averages of PEP, HR, SBP, and DBP assessed during each 2.8-min task period constituted task scores (Cronbach's $\alpha > 0.98$). Cardiovascular reactivity scores were computed by subtracting baseline scores from their respective task scores (see Llabre *et al.*, 1991, Kelsey *et al.*, 2007).

For zygomaticus major muscle reactivity, we computed a mean score and a maximum score as primary EMG measures (Fridlund and Cacioppo, 1986; Tassinary *et al.*, 2007). For the mean score, a baseline was computed as the average of all data points assessed during a 2-s rest period following the last task trial, just before participants were informed that they had obtained the reward. A reward mean score was computed as the average of all data points assessed during the first 2 s of the period when participants were told they had obtained the reward. The difference between the reward and baseline scores constituted the reactivity mean score. The maximum score was computed with the same procedure, using the maximum value of each period to calculate the

Table 1. Means and standard errors of cardiovascular baseline values

	M (s.e.)		
	PEP neutral	PEP reward	PEP punishment
Non-depressed	105.35 (4.35)	105.36 (4.52)	105.97 (4.61)
Depressed	106.40 (3.75)	106.68 (3.10)	105.77 (3.63)
	HR neutral	HR reward	HR punishment
Non-depressed	72.94 (1.80)	72.56 (1.63)	71.78 (1.64)
Depressed	77.94 (2.23)	76.90 (2.02)	77.44 (2.29)
	SBP neutral	SBP reward	SBP punishment
Non-depressed	117.64 (2.73)	113.75 (2.50)	113.01 (2.63)
Depressed	123.00 (2.45)	121.97 (2.98)	120.56 (2.91)
	DBP neutral	DBP reward	DBP punishment
Non-depressed	73.47 (1.98)	70.32 (2.06)	70.29 (1.84)
Depressed	79.45 (2.02)	78.53 (2.54)	78.18 (2.35)

Note. PEP is indicated in milliseconds, HR is indicated in beats per minute, and SBP and DBP are indicated in millimeters of mercury. For cardiovascular baseline values, the terms neutral, reward, and punishment refer to the baseline periods preceding the experimental tasks under neutral, reward, and punishment instructions, respectively.

Table 2. Means and standard errors of EMG baseline values

	M (s.e.)			
	Reward (zygomaticus major)		Punishment (corrugator supercillii)	
	EMG mean	EMG maximum	EMG mean	EMG maximum
Non-depressed	0.43 (0.14)	0.88 (0.25)	0.08 (0.02)	0.18 (0.04)
Depressed	0.17 (0.02)	0.38 (0.05)	0.21 (0.07)	0.44 (0.16)

Note. EMG is indicated in microvolts. The terms reward and punishment refer to the baseline periods preceding the receipt of the reward and punishment, respectively.

baseline maximum score, the reward maximum score, and the reactivity maximum score. Corrugator supercillii muscle reactivity was calculated correspondingly.

We focused on our *a priori* hypotheses and performed focused comparisons (independent samples *t* tests) (see Rosenthal and Rosnow, 1985) to compare MDD and control participants' responses for each of the experimental parts. To protect against Type I errors, we used Bonferroni-adjusted significance levels: $\alpha < 0.017$ for cardiovascular baseline scores, reactivity scores, and performance measures, because we performed one *t* test for each of the three parts; $\alpha < 0.025$ for EMG baseline and reactivity scores, because we performed one *t* test for each of the two highly similar mean and maximum reactivity scores. The significance level for the self-report questions was kept at $\alpha < 0.05$, as the questions differed in the reward and punishment parts.

Results

Preliminary analyses

Means and standard errors of the cardiovascular baseline values appear in Table 1. No significant differences emerged between the MDD and control groups for the neutral, reward, and punishment PEP baseline scores, $t_s < 1$, $p_s > 0.81$. Concerning our secondary cardiovascular measures, there were no significant group differences for SBP, DBP, and HR baseline scores, $t_s < 2.13$, $p_s > 0.04$, but for DBP

reward baseline, $t_{(35)} = 2.52$, $p = 0.016$, $\eta^2 = 0.13$, and DBP punishment baseline scores, $t_{(35)} = 2.66$, $p = 0.012$, $\eta^2 = 0.17$. MDD patients' EMG baselines did not significantly differ from control participants, $t_s < 1.92$, $p_s > 0.06$ (see Table 2).

Concerning cardiovascular reactivity in the neutral condition, MDD patients (PEP: $M = -3.43$, $s.e. = 1.62$; SBP: $M = 1.88$, $s.e. = 1.03$; HR: $M = 1.31$, $s.e. = 0.61$) did not significantly differ from control participants (PEP: $M = -7.58$, $s.e. = 1.67$; SBP: $M = 4.84$, $s.e. = 1.25$; HR: $M = 3.23$, $s.e. = 1.20$) on PEP, SBP, and HR reactivity, $t_s < 1.82$, $p_s > 0.07$. However, MDD patients ($M = 0.69$, $s.e. = 0.45$) had lower DBP reactivity than control participants ($M = 3.33$, $s.e. = 0.85$), $t_{(35)} = 2.69$, $p = 0.011$, $\eta^2 = 0.18$.

Additionally, there were significant effects on the number of correct responses, $t_{(30,36)} = 3.12$, $p = 0.004$, $\eta^2 = 0.20$ (adjusted *dfs* because of differing variances), and reaction times (in milliseconds), $t_{(38)} = 2.64$, $p = 0.012$, $\eta^2 = 0.22$, in the neutral condition: MDD patients gave fewer correct responses ($M = 10.00$, $s.e. = 0.46$) and answered more slowly ($M = 2049.51$, $s.e. = 135.54$) than non-depressed participants (correct responses: $M = 11.65$, $s.e. = 0.26$; reaction times: $M = 1622.30$, $s.e. = 88.29$).

Reward anticipation

Results revealed a significant effect for PEP, our main dependent cardiovascular variable, $t_{(34,84)} = 2.58$, $p = 0.014$, $\eta^2 = 0.15$. As

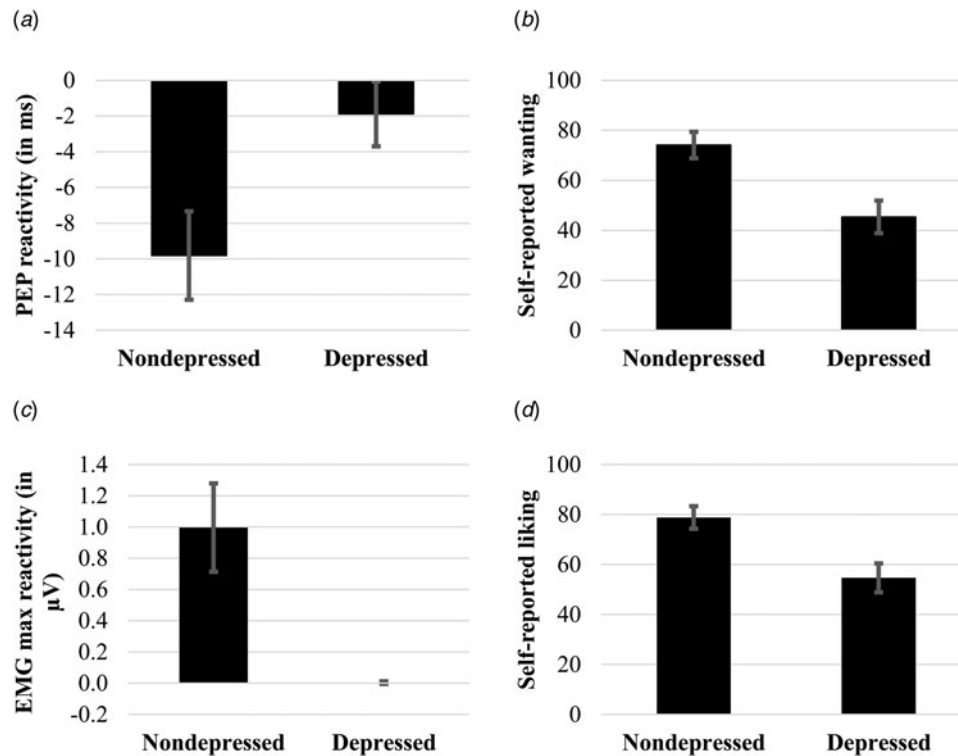


Fig. 1. Means and standard errors of (a) PEP reactivity and (b) self-reported wanting during reward anticipation, and of (c) EMG zygomaticus major maximum reactivity and (d) self-reported liking during reward consumption.

expected, PEP reactivity was weaker in MDD patients ($M = -1.88$, $S.E. = 1.82$) than in control participants ($M = -9.81$, $S.E. = 2.48$) (see Fig. 1a). The t test for SBP reactivity fell short of the adjusted significance level, $t_{(22,33)} = 2.27$, $p = 0.033$, $\eta^2 = 0.13$. Nevertheless, the finding mirrored PEP results insofar as SBP reactivity in MDD patients ($M = 2.00$, $S.E. = 0.60$) was weaker than in control participants ($M = 6.09$, $S.E. = 1.70$). No reliable group differences emerged for HR and DBP reactivity, $ts < 1.92$, $ps > 0.06$ (MDD patients' HR: $M = 1.72$, $S.E. = 0.74$; control participants' HR: $M = 3.99$, $S.E. = 1.18$; MDD patients' DBP: $M = 1.45$, $S.E. = 0.59$; control participants' DBP: $M = 3.23$, $S.E. = 0.71$).

As expected, also the subjective motivation to obtain the reward was weaker in the MDD group ($M = 45.35$, $S.E. = 6.52$) than in the control group ($M = 74.10$, $S.E. = 5.27$), $t_{(38)} = 3.43$, $p < 0.001$, $\eta^2 = 0.23$ (see Fig. 1b). Moreover, MDD patients gave fewer correct responses ($M = 9.60$, $S.E. = 0.55$) than non-depressed individuals ($M = 12.05$, $S.E. = 0.23$), $t_{(25,60)} = 4.07$, $p < 0.001$, $\eta^2 = 0.30$. The difference in global reaction times fell short of the adjusted significance level, $t_{(34,44)} = 2.07$, $p = 0.046$, $\eta^2 = 0.10$. MDD patients tended to answer more slowly ($M = 1817.42$, $S.E. = 105.08$) than non-depressed individuals ($M = 1549.31$, $S.E. = 75.30$).

Reward consumption

MDD patients showed significantly weaker zygomaticus maximum reactivity ($M = 0.0035$, $S.E. = 0.0083$) than non-depressed participants ($M = 0.9960$, $S.E. = 0.2829$), $t_{(19,03)} = 3.51$, $p = 0.002$, $\eta^2 = 0.24$ (see Fig. 1c). Similarly, MDD patients' mean zygomaticus reactivity was significantly weaker ($M = 0.0003$, $S.E. = 0.0016$) than that of non-depressed participants ($M = 0.1105$, $S.E. = 0.0436$), $t_{(19,05)} = 2.52$, $p = 0.020$, $\eta^2 = 0.14$. Further supporting

the predictions, MDD patients reported less reward liking ($M = 54.65$, $S.E. = 5.78$) than non-depressed participants ($M = 78.80$, $S.E. = 4.50$), $t_{(38)} = 3.30$, $p = 0.002$, $\eta^2 = 0.22$ (see Fig. 1d).

Punishment anticipation

As expected, MDD patients showed weaker PEP reactivity ($M = 1.06$, $S.E. = 1.63$) than non-depressed participants ($M = -12.04$, $S.E. = 3.47$), $t_{(26,95)} = 3.41$, $p = 0.002$, $\eta^2 = 0.23$ (see Fig. 2a). Moreover, MDD patients also showed blunted reactivity of SBP, $t_{(26,55)} = 2.83$, $p = 0.009$, $\eta^2 = 0.19$ (MDD patients: $M = 1.50$, $S.E. = 0.62$; non-depressed participants: $M = 5.37$, $S.E. = 1.22$), and DBP, $t_{(35)} = 2.76$, $p = 0.009$, $\eta^2 = 0.19$ (MDD patients: $M = 0.49$, $S.E. = 0.74$; non-depressed participants: $M = 3.75$, $S.E. = 0.92$). No significant difference emerged for HR reactivity, $t_{(27,88)} = 1.89$, $p = 0.069$, $\eta^2 = 0.16$ (MDD patients: $M = 1.88$, $S.E. = 0.65$; non-depressed participants: $M = 4.64$, $S.E. = 1.31$).

Self-reported motivation to avoid punishment did not significantly differ between the MDD ($M = 58.15$, $S.E. = 6.72$) and control groups ($M = 67.90$, $S.E. = 4.96$), $t_{(38)} = 1.17$, $p = 0.250$ (see Fig. 2b). Moreover, MDD patients tended to give fewer correct responses ($M = 10.55$, $S.E. = 0.41$) than non-depressed participants ($M = 11.75$, $S.E. = 0.27$), $t_{(38)} = 2.46$, $p = 0.019$, $\eta^2 = 0.13$, and their responses were significantly slower ($M = 1825.72$, $S.E. = 102.22$ v. $M = 1498.03$, $S.E. = 80.65$), $t_{(38)} = 2.52$, $p = 0.016$, $\eta^2 = 0.14$ (significance level of $\alpha < 0.017$).

Punishment consumption

No significant group differences emerged for the two corrugator reactivity scores, $ts < 1.01$, $ps > 0.31$ (corrugator maximum reactivity: MDD patients' $M = 0.0536$, $S.E. = 0.0202$ v. control

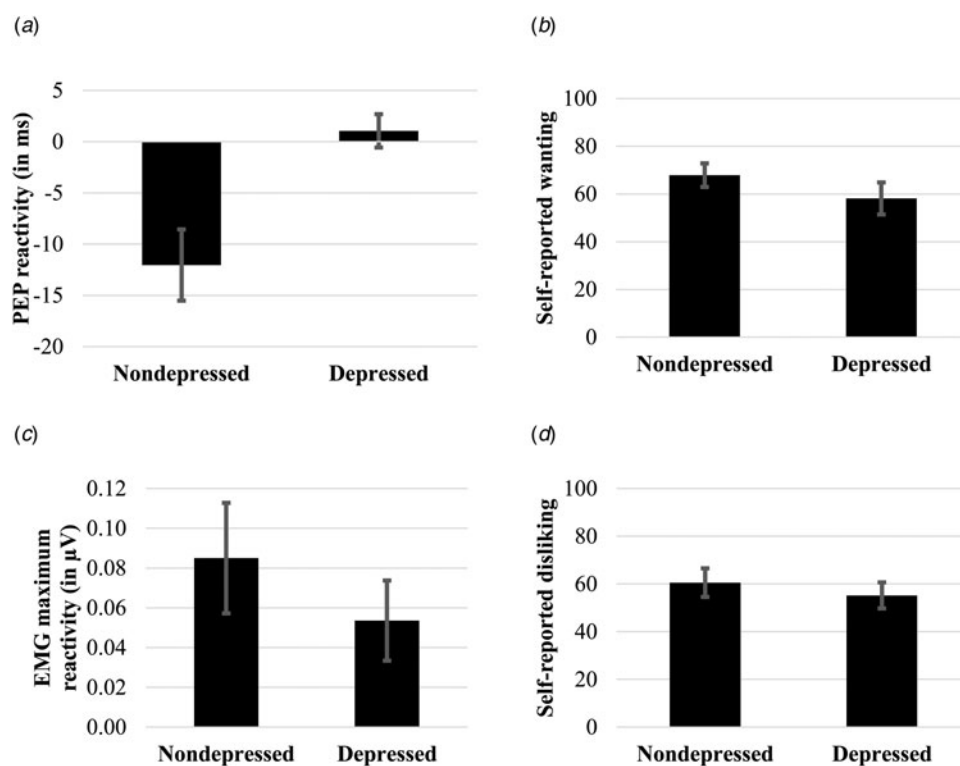


Fig. 2. Means and standard errors of (a) PEP reactivity and (b) self-reported motivation to avoid during punishment anticipation, and of (c) EMG corrugator supercilii maximum reactivity and (d) self-reported disliking during punishment consumption.

participants' $M = 0.0850$, $S.E. = 0.0278$; corrugator mean reactivity: MDD patients' $M = 0.0041$, $S.E. = 0.0024$ *v.* control participants' $M = 0.0078$, $S.E. = 0.0028$). Moreover, MDD patients ($M = 55.20$, $S.E. = 5.45$) reported a similar level of displeasure as non-depressed participants ($M = 60.55$, $S.E. = 5.98$) during punishment consumption, $t_{(38)} = 0.66$, $p = 0.513$ (see Figs 2c and 2d).

Discussion

To our knowledge, this is the first study testing hypotheses about reward and punishment responsiveness by means of effort-related cardiovascular reactivity during incentive anticipation and affective facial muscular responses during incentive consumption in patients with MDD. Self-report measures complement this multi-method approach.

Components of reward and punishment processing

Concerning reward and punishment *anticipation*, cardiovascular and self-reported results support our predictions, demonstrating that MDD patients showed reduced subjective motivation to obtain a reward but similar motivation to avoid a punishment. In contrast, MDD patients mobilized less effort during both reward and punishment anticipation. These findings are in line with previous self-report studies focusing on reward (Chentsova-Dutton and Hanley, 2010) or punishment (Layne, 1980) responsiveness in depression.

On the behavioral level, complementary results also show impairments in the anticipatory component. These results are in accordance with previous behavioral studies (e.g. Pizzagalli *et al.*, 2009b; Treadway *et al.*, 2012). Performance decrements also emerged under neutral conditions. This may suggest a

general cognitive deficit in depression, irrespective of the incentive structure of the task (see Gotlib and Joormann, 2010, for a review). On the other hand, effort is only one factor among others (e.g. ability and strategy use) that influences task performance outcomes (Locke and Latham, 1990).

Our results also support our differential predictions for affective responses during the *consumption* of reward and punishment. MDD patients showed reduced affective facial responses and reported less pleasure during the reward message, indicating a generally reduced affective response to reward receipt in depression. In contrast, MDD patients showed similar affective facial responses and similar displeasure during punishment. This congruence between facial EMG measures and subjective evaluations is in line with previous studies (Lang *et al.*, 1993).

Implications for punishment

Punishment responsiveness in depression is less studied than reward responsiveness and findings are to some extent inconsistent (see Eshel and Roiser, 2010, for a review). These inconsistencies may be due to two factors. First, the process of punishment responsiveness is not always considered as consisting of two different phases (i.e. anticipation and consumption). Second, punishment responsiveness in depression might depend on the levels of analysis. We suggest that impairments concern only the effort that depressed individuals mobilize for avoiding punishment. In contrast, depressed individuals indicate subjective avoidance motivation and show similar affective responses to the receipt of punishment.

This differential response pattern during punishment anticipation is presumably due to passive avoidance behavior in depression

(see Ottenbreit and Dobson, 2004, for a review). Specifically, the motivation to avoid punishment seems to translate into active and effortful avoidance in non-depressed individuals but into passive and thus effortless avoidance in depressed individuals. The inconsistencies of previous studies on punishment responsiveness might be due to a lack of differentiation regarding the temporal course of punishment processing and, importantly, to a lack of differentiation between the subjective motivation to avoid a punishment on the one hand and the objective, physiological response on the other hand.

These results have important implications. On the diagnostic level, it is important to differentiate not only between positive and negative incentives but also between anticipatory *v.* consummatory responses, and, finally, between self-report, behavioral, and physiological responses. This might lead to different therapeutic avenues. Whereas approaches like behavioral activation (e.g. Cuijpers *et al.*, 2007) might be suitable for treating deficits in reward responsiveness, passive responses to punishment require working on the implicit behavioral and physiological level, rather than on explicit recognition of to-be-avoided negative consequences. In the case of punishment, comorbid anxiety should also be taken into consideration.

Limitations and future directions

One limitation of the present study is its descriptive character. Even if descriptive data are indispensable to identify and specify impairments in depressed individuals' behavior, future studies might take this approach a step further and investigate the underlying psychological mechanisms more profoundly.

Furthermore, even if a medication that could affect the cardiovascular system was an exclusion criterion for both depressed and healthy participants, most of the MDD patients were on antidepressant medication. As antidepressant medication can restore responsiveness to incentives (Stoy *et al.*, 2012), it would be important for future research to test our predictions in medicated *v.* unmedicated patients or in a pre-post treatment design.

Finally, in compliance with the conception of *unclear task difficulty* in motivational intensity theory (Brehm and Self, 1989), the present study aimed at emphasizing subjective success importance and at minimizing the salience of task difficulty perceptions. However, we cannot completely exclude that MDD patients perceived the task as more demanding and their capacities as lower. Depending on the type of task, this might have led to stronger or weaker effort mobilization (Brinkmann and Gendolla, 2007, 2008). Future research might benefit from assessing task demand appraisals in the context of incentive responsiveness in a clinical sample.

Conclusions

The results of the present study demonstrate a differential response pattern on different levels of analysis during incentive processing in depression. We interpret our findings as suggesting that depression is linked to reduced approach motivation and to passive avoidance motivation as well as to reduced affective responses to positive but not negative outcomes.

Supplementary material. The supplementary material for this article can be found at <https://doi.org/10.1017/S0033291718001526>.

Acknowledgements. We wish to thank all patients and control participants for their participation in the present study.

Author contributions. J. F. and K. B. designed the study. J. F. collected all data and performed the data processing and data analyses. J. F. and K. B. drafted the first version of the manuscript. G. H. E. G. and O. S. contributed to the study design as well as to additional writing, editing, and revising of the manuscript. All authors approved the final version of the paper for submission.

Financial support. This research was supported by a grant from the Swiss National Science Foundation (SNF 100014-134557) awarded to K. B..

Conflict of interest. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. All procedures were approved by the Central Ethics Committee of the University Hospitals of Geneva.

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