CORTEX 202 (2026) 130–151

Available online at www.sciencedirect.com

ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Research Report

Subliminal facial primes bias emotion judgments during naturalistic videos in major depressive disorder

Julia Schräder [a,b,f,*], Rebecca Sieberg [a], Felix Menne [c], Felix Dörr [c], Johannes Tröger [c], Ute Habel [a,d], Alexandra König [c,e] and Lisa Wagels [a,b,f]

[a] Institute for Translational Neuroscience and Clinical Psychology, Faculty of Medicine, RWTH Aachen, Aachen, Germany
[b] JARA-Translational Brain Medicine, Aachen, Germany
[c] ki:elements GmbH, Saarbrücken, Germany
[d] Institute of Neuroscience and Medicine, JARA-Institute Brain Structure Function Relationship (INM 10), Research Center Jülich, Jülich, Germany
[e] Université Côte d'Azur, Centre Hospitalier et Universitaire, Clinique Gériatrique du Cerveau et du Mouvement, Centre Mémoire de Ressources et de Recherche, Nice, France
[f] Center for Computational Life Science, RWTH Aachen University, Germany

ARTICLE INFO

Article history:
Received 19 December 2025
Revised 6 May 2026
Accepted 28 May 2026
Action editor Pia Rotshtein
Published online 6 June 2026

Keywords:
Depression
Mood-congruent bias
fMRI
Speech
Emotion processing

ABSTRACT

Emotional information is typically encountered in dynamic and context-rich environments, yet mood-congruent bias in major depressive disorder (MDD) has largely been studied using static stimuli. Subliminal emotional information modulations on behavioral and neural responses are investigated using a novel dynamic emotional video processing paradigm. In total, 126 participants (MDD: $n = 60$, Control: $n = 66$) completed an fMRI task in which happy or sad videos were presented while subliminal facial expressions (happy/sad; 16.7 msec) were flashed every second. Participants categorized video emotion (happy/sad/neutral) and rated subjective affect after each video. Outside the scanner, participants narrated positive and negative autobiographical events; speech features were extracted and tested for associations with questionnaire measures moderated by group. Across participants, emotionally congruent video-prime pairings were associated with faster and more accurate emotion judgments and increased activation in visual cortical regions during both happy and sad video processing. Incongruent pairings elicited broader recruitment of frontal, parietal, and temporal. Compared to healthy controls, MDD showed slower responses and increased activation in right occipito-temporal regions during video viewing. MDD show reduced accuracy during sad-prime/happy-video relative to congruent happy trials, while HC showed no prime effect on accuracy. No group-by-condition interaction was observed at the neural level. After correction for multiple comparisons, speech –questionnaire associations were not significantly moderated by group. Depression is characterized by reduced processing efficiency and increased perceptual-attentional demands during unconscious emotional conflict, particularly when happy videos are disrupted by sad unconscious stimuli. This supports an unconscious mood-congruent processing bias.

* *Corresponding author*. Institute for Translational Neuroscience and Clinical Psychology, Faculty of Medicine, RWTH Aachen, Wendlingweg 2, 52074, Aachen, Germany.
E-mail address: jschraeder@ukaachen.de (J. Schräder).
https://doi.org/10.1016/j.cortex.2026.05.015

1. Introduction

Major depressive disorder (MDD) is a leading cause of disability and is characterized not only by persistent low mood and anhedonia, but also by systematic alterations in how emotional information is perceived and evaluated (De Raedt & Koster, 2010; Disner et al., 2011; Gong & He, 2015; Gotlib & Joormann, 2010). A large body of work suggests that emotional context can bias attention, interpretation, and cognitive control in ways that maintain or intensify depressive symptoms (Duque & Vázquez, 2015; Elliott et al., 2002; Everaert et al., 2012, 2012, 2012; Fan et al., 2024; Gotlib et al., 2004, 2004, 2004; Joormann & Siemer, 2011). However, much of the experimental evidence is derived from simplified laboratory paradigms using static, isolated cues. Because everyday emotion perception is dynamic and context-dependent, extending bias research to more naturalistic settings is important for understanding how these mechanisms operate in real-world social environments and for identifying objective markers that might support clinical assessment.

1.1. *(Biased) emotion processing in depression*

A key aspect of depression research focuses on mood-congruent biases, where individuals' information processing is influenced by their emotional state, affecting attention, memory, interpretation, and cognitive control (Disner et al., 2011; Everaert et al., 2012; Stuhrmann et al., 2013, 2013; Yang et al., 2011; M. Zhang et al., 2020). Neuroimaging findings support the assumption that this bias exists even unconsciously (Schräder et al., 2024), which is marked by increased neurological responses, such as elevated amygdala activity and event-related potentials, intensifying the focus on negative information (Arnone et al., 2012; Schräder et al., 2024; Stuhrmann et al., 2013; Zhang et al., 2016; M. Zhang et al., 2020). These biases lead to focus on, interpret, and remember negative information more intensely, which may exacerbate depressive symptoms (Gotlib et al., 2004; Gotlib & Joormann, 2010; Schräder et al., 2024). While most studies have utilized static cues, this study pivots to dynamic stimuli which more closely mimic real-world interactions, offering a more accurate assessment of emotional processing (Ack Baraly et al., 2020; Aviezer et al., 2017). To better understand emotion processing in depression, real life like videos incorporating facial expressions offer a more ecologically valid approach (Courtney et al., 2010; Hu et al., 2020; Wang et al., 2023). Importantly, the shift to dynamic, naturalistic stimuli may not merely replicate findings from static paradigms but could reveal qualitatively different patterns of emotional bias. The type of stimuli employed determines the nature of observed biases, with dynamic paradigms revealing a selective reduction in happiness recognition in MDD that static tasks fail to capture (Bomfim et al., 2019). Multimodal analysis, which combines (neuro)physiological data streams, is used to assess emotional responses and their underlying processing mechanism to these dynamic stimuli (Ack Baraly et al., 2020; Courtney et al., 2010).

1.2. *Objective neural and speech markers of depressive symptoms*

Recent research examined emotion and cognition in depression using neuroimaging studies (Diener et al., 2012), highlighting consistent patterns of hypoactivity in the dorsolateral prefrontal cortex (DLPFC) and rostral anterior cingulate cortex (rACC) associated with cognitive impairments. Reduction in cognitive functioning could be linked to attentional biases in depression (i.e., rumination or attention inhibition deficits towards negative cues) (De La Peña-Arteaga et al., 2021; De Raedt & Koster, 2010). Dysfunctions in MDD additionally manifest as hyperactivity in limbic structures like the amygdala (Arnone et al., 2012; Rauch et al., 2010; Stuhrmann et al., 2013; Victor et al., 2010; Zhong et al., 2011), leading to potential deficits in emotion regulation (De Raedt & Koster, 2010). Neuroimaging studies indicate that interactions between the cortical and limbic systems play a critical role in the onset of depression (Alders et al., 2019; Kaiser et al., 2015; Lemke et al., 2022). Although the exact causes of depression are not universally agreed upon, a dysfunction in form of reduced activity and connectivity within limbic systems is considered (Helm et al., 2018; Lemke et al., 2022) along with increased volume in hippocampal regions (Besteher et al., 2019; Frodl et al., 2008; O'Shea et al., 2018). These findings suggest that MDD involves complex interactions between cortical and limbic systems, leading to significant emotional and cognitive impairments and a mood congruent bias.

Given the highly heterogeneous nature of depression, relying on single neurophysiological biomarkers may not adequately capture the complexity of this condition (Gong & He, 2015; Thapar et al., 2022). Objective markers are extensively studied, for example through EEG (Fang et al., 2022; D. Zhang et al., 2016; J. Zhang et al., 2021; Zhu et al., 2018), functional magnetic response imaging (fMRI) (Bracht et al., 2015; Enneking et al., 2020; Hall et al., 2014; Rogers et al., 2004; Schlösser et al., 2008; Stuhrmann et al., 2013), behavior (Alders et al., 2019; Esteban et al., 2019; M. Zhang et al., 2020), genetics (Flint & Kendler, 2014; Markus, 2013), environmental influence (Saveanu & Nemeroff, 2012) and psychological states (L. A. Loeffler et al., 2018; L. A. K. Loeffler et al., 2019; Rogers et al., 2004). Another approach to establish objective markers for depression are speech patterns that are suggestive of the disease and its status (Menne et al., 2024). It has been demonstrated that decreased verbal productivity, diminished prosody, and monotonous, "lifeless" speech are indicative of depression (Cummins et al., 2015; Mundt et al.,

2007). Changes in speech quality to a hollow and toneless sound have been associated with increased suicidal ideation (Scherer et al., 2016). It was also found that mood improvement was related to improved verbal fluency (Douglas & Porter, 2009). Literature has shown significant correlations between depression severity and pause-related speech measures, demonstrating that depressed individuals struggle with word selection (Alpert et al., 2001; Mundt et al., 2007, 2012). The described speech characteristics provide valuable markers that can enhance automated diagnostic systems for mental health assessment, which is measured cheaply, remotely, non-invasively. Furthermore, evaluation can be done independently without relying on subjectively self-reports and demonstrate comparable reliability in classifying individuals with and without MDD (Menne et al., 2024).

In this study, a multimodal approach is used to investigate how emotional and cognitive biases interact and contribute to alterations in speech, neurophysiology, behavioral and emotion regulation strategies in MDD. The aim is to test whether processing biases in MDD can be found in a more naturalistic setting, using dynamic emotional cues. Two foundations of mood-congruent biases are investigated: (i) An emotional processing bias in depression is assumed to be reflected in behavioral and neural responses. Specifically, MDD participants are expected to respond more quickly to videos depicting sadness than happiness, while HCs are anticipated to show the opposite pattern. Subconscious emotional priming, particularly using sad emotional faces, is expected to have a stronger impact on MDD participants than on HCs, potentially leading to reduced task performance. MDD are expected to show increased brain activity in limbic brain regions while video watching compared to HC. The emotional processing bias in MDD is expected to be reflected by an increased use of negative words compared to HC and higher speech production in negative compared to positive context. (ii) A reduction in cognitive functioning in MDD is particularly expected to be reflected in executive processes (verbal fluency and cognitive control). Reduced DLPFC and rACC activity in MDD (Diener et al., 2012) aligns with findings that impaired cognitive flexibility and executive functioning reduction (Rock et al., 2014; Snyder, 2013) and reduced cognitive control is associated with depression (Grahek et al., 2019; Loeffler et al., 2019). Consequently, any observed increases in activity in these regions during subconscious emotional priming may represent a compensatory mechanism, aiming to offset these cognitive deficits in MDD as detected by fMRI. Reduced cognitive functioning in MDD is expected to be reflected by reduced verbal fluency. To address the relationship between speech markers and general emotion regulation strategies, psychological questionnaire data will be associated with speech markers.

2. Methods

2.1. Participants

126 participants were measured: 66 HC (29 men, 37 women, mean age of 25.89 years, SD = 6.48, median = 24 years, range = 19–52 years) and 60 MDD (29 men, 31 women, mean age of 25.90 years, SD = 6.04, median = 23.5 years, range 18–41 years). Participants aged 18–55, fluent in German, and right-handed were included. Exclusion criteria were chronic or acute illness or psychiatric disorders (except depression) according to the DSM-V (Falkai et al., 2018) screened using the Structured Clinical Interview 5 for DSM-V Disorders (SCID-5; Beesdo-Baum et al., 2019). Those diagnosed with depression were included in the MDD group (41 with medication, 18 without, 1 unknown). Of those receiving pharmacological treatment, 20 (33.3%) were treated with an SSRI, 8 (13.3%) with an SNRI, and 4 (6.7%) with an NDRI. Combination therapies included SSRI + NaSSA (n = 5, 8.3%), SNRI + NaSSA (n = 1, 1.7%), and SSRI + NDRI (n = 1, 1.7%). One participant each (1.7%) received NaSSA monotherapy, SSRE monotherapy (Tianeptine), or another agent (Opipramol). The effects of medication on task performance were examined in an additional GLM restricted to the MDD group. Medication status did not yield any significant effects, and the pattern of results remained consistent with those reported in the main analysis (Table S11). According to the Declaration of Helsinki, participants gave written informed consent and were informed about the study before examination. The study was approved by the local ethics committee of the RWTH Aachen University Hospital "Independent Ethics Committee" (Ethik-Kommission) of the Faculty of Medicine" (EK 045/19).

2.2. Neurophysiological and cognitive assessment

Demographic information was assessed. Severity of depressive symptoms was measured based on self-reports using the Becks Depression Inventory-II (BDI-II) (Beck et al., 1996) and (additionally in the MDD group) via the Hamilton Rating Scale for Depression (HAMD) (Williams, 1988). The Mehrfach-Wortschatz-Intelligenztest (MWT-B) for estimation of intelligence, one subset (Digit Span) of the Wechsler-Memory-Scale (WMS-R) (Wechsler & Härting, 2000) to measure short-term and working memory and the Trail Making Test (TMT A/B) (Reitan, 1971) for general executive functions were used. Clinical data such as trait and state of fear (State/Trait Anxiety Inventory; STAI 1/2) (Spielberger et al., 2001), alexithymia (the Bermond-Vorst Alexithymia Questionnaire, BVAQ) (Vorst & Bermond, 2001) and emotion regulation (Difficulties in Emotion Regulation Scale, DERS) (Dan-Glauser & Scherer, 2012); Cognitive Emotion Regulation Questionnaire (CERQ) (Loch et al., 2011) were assessed (Table 1). Group differences in neurophysiological assessment are reported in a previous publication (Schräder et al., 2024).

2.3. Study procedure

For a detailed description of the procedure, see Supplements (Fig. S1). This preregistered study (OSF; https://osf.io/yt6gr, updated: https://osf.io/jv5h2) extends a previous study (Schräder et al., 2024) by analyzing the second task from the concurrent EEG-fMRI dataset.

First, participants were performed in a speech task narrating positive and negative life events. Afterwards, they were placed in the fMRI scanner while simultaneously recording EEG. After T1 images were acquired, they performed

Table 1 – Descriptive statistics (mean ± SD) for the Major Depressive Disorder group (MDD) and healthy control group (HC), along with results from independent samples Welch's *t*-tests, effect sizes (Cohen's *d*), and Bonferroni-corrected *p*-values.

Variable	MDD Mean ± SD	HC Mean ± SD	t	d	p*
Age	25.43 ± 5.48	26.47 ± 7.03	−.829	−.165	>.999
Sex	1.53 ± .50	1.45 ± .50	.791	.158	>.999
WMS	28.12 ± 3.80	28.84 ± 3.69	−.962	−.192	>.999
TMT-A (time)	18.82 ± 3.44	21.17 ± 5.82	−2.453	−.486	.440
TMT-B (time)	47.99 ± 15.29	49.67 ± 20.40	−.463	−.093	>.999
DigitSpan forward total	11.48 ± 2.31	11.51 ± 2.56	−.063	−.013	>.999
DigitSpan backward total	7.90 ± 2.56	8.10 ± 2.53	−.395	−.079	>.999
BVAQ	57.51 ± 11.38	48.33 ± 7.44	4.753	.959	<.001
BDI-II	24.76 ± 11.16	4.04 ± 3.73	12.345	2.510	<.001
STAI trait	64.39 ± 8.41	39.35 ± 6.88	16.260	3.266	<.001
STAI state	58.41 ± 9.92	42.80 ± 6.67	9.194	1.853	<.001
DERS total	109.98 ± 19.44	65.65 ± 15.86	12.466	2.504	<.001
DERS non Acceptance of emotional reactions	17.29 ± 5.69	10.98 ± 4.75	6.002	1.205	<.001
DERS goals difficulties	17.86 ± 3.79	10.61 ± 3.38	10.083	2.022	<.001
DERS impulse control difficulties	14.35 ± 5.32	8.45 ± 2.72	6.937	1.404	<.001
DERS lack of emotional awareness	18.57 ± 5.32	14.65 ± 4.44	3.997	.802	.003
DERS limited emotion regulation	26.84 ± 6.19	12.25 ± 5.00	12.930	2.598	<.001
DERS lack of emotional clarity	15.08 ± 5.05	8.71 ± 2.36	8.036	1.628	<.001
CERQ self-blame	13.45 ± 3.75	9.67 ± 2.99	5.564	1.118	<.001
CERQ acceptance	13.20 ± 3.16	13.43 ± 2.85	−.377	−.076	>.999
CERQ rumination	12.51 ± 3.27	9.82 ± 3.12	4.201	.841	.002
CERQ positive refocusing	7.51 ± 2.71	11.39 ± 3.61	−6.102	−1.214	<.001
CERQ refocusing on planning	12.71 ± 3.69	15.86 ± 3.03	−4.654	−.935	<.001
CERQ positive reappraisal	10.02 ± 3.11	14.84 ± 3.72	−7.046	−1.404	<.001
CERQ putting into perspective	10.18 ± 3.31	14.59 ± 3.48	−6.486	−1.296	<.001
CERQ catastrophizing	9.20 ± 3.17	5.96 ± 2.07	6.035	1.217	<.001
CERQ blaming others	8.22 ± 3.29	7.16 ± 2.98	1.699	.341	>.999
Hamilton depression score	18.44 ± 5.91				

Note. *p-value is corrected for multiple comparison using Bonferroni correction for 27 tests (new $\alpha = .0018$).

a backward mask task (as part of the previous study) and a subliminal video priming task which is part of this study.

2.4. *Subliminal video priming task*

A novel video-based paradigm was used to assess unconscious mood-congruent biases in a naturalistic setting (Fig. 1). Participants watched emotionally charged videos (happy or sad) while EEG-fMRI data was recorded. The videos were taken from the DEVO dataset (Ack Baraly et al., 2020), featuring clips to minimize familiarity and bias, pre-rated for arousal and valence, and categorized as positive or negative. During video presentation, subliminal prime faces (happy or sad; taken from the FACE database (Ebner et al., 2010)) were presented every second. These primes were either congruent or incongruent with the video content, creating a unique opportunity to investigate how participants unconsciously respond to emotional stimulus match or mismatch.

Each trial began with a 300 msec fixation cross, followed by videos interspersed with subliminal primes (16.7 msec) every second, influencing unconscious emotional processing. This presentation time was used based on a previous pilot study examining the optimal presentation time for unconscious image presentation of facial expressions (Schräder et al., 2023). A response screen was presented for 1.5 sec. Participants were instructed to rate the video emotion by pressing one of three response buttons (happy, sad, or neutral). In a second response window, participants indicated on a scale from zero to nine how the video made them feel, where zero represented "very sad", nine represented "very happy", and five indicated a neutral feeling. A fixation cross was presented for between 2 sec and 3 sec as an inter-stimulus interval serving as jitter.

Prime-video pairs were divided into two categories: emotionally congruent or incongruent, creating an event-related 2 × 2 design (happy/sad primer × happy/sad target). This factorial structure allows the statistical separation of main valence effects from emotional congruency effects via the interaction term, thereby isolating mismatch-related processing from general positive or negative stimulus processing. Participants completed two practice trials with neutral videos. The main task consisted of one block with 60 trials in pseudorandomized order (20 trials per condition). The task lasted 12 min.

2.5. *Behavioral effects of subliminal priming during emotional video processing*

Performance differences by group and condition were analyzed using linear mixed models (LMMs) using lme4 (Bates, 2007), with Bonferroni-corrected post hoc tests within the emmeans package to account for multiple comparisons (Searle et al., 1980).

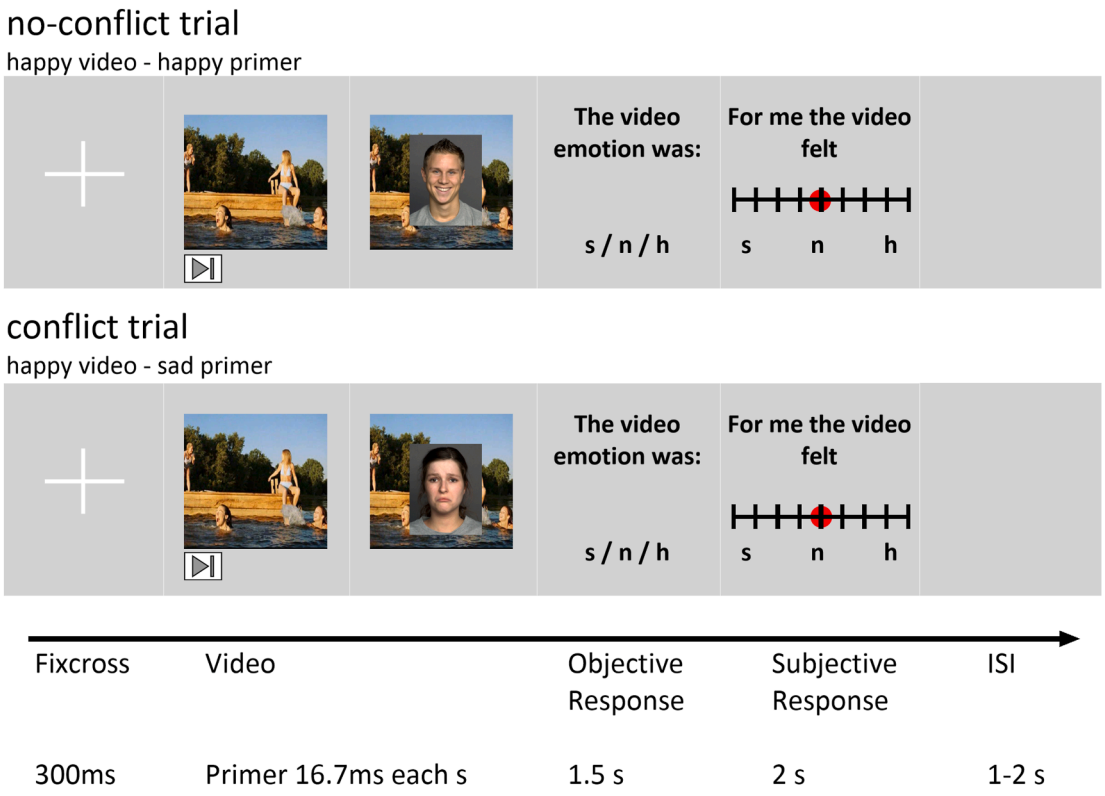

Fig. 1 – Full trial of the subliminal video priming task. The emotional expression of primer/video is either the same (no-conflict trial) or different (conflict trial). The present emotions were either "happy" or "sad". Participants classified the emotion of the video as either "happy", "sad", or "neutral" before they give a subjective rating ranging from "sad" to "happy". "h", happy; "n", neutral; "s", sad.

2.5.1. *Reaction time and accuracy during emotional video classification*

Participants were instructed to rate the emotional content of the videos by categorizing them as happy, sad, or neutral (objective rating). The model incorporated the main and interacting effects of the task condition (happy/sad primer × happy/sad video) and group (HC/MDD). Age and sex were included as fixed effects. A random intercept was added for each participant (ID).

$$\text{model1/2} \leftarrow \text{lmer}(\text{rt/accuracy} \sim \text{task condition*group} + \text{age} + \text{sex} + (1|\text{ID}))$$

To examine whether individual differences in task performance were associated with self-reported emotional symptoms, accuracy, or reaction time, linear mixed-effects models. Percent accuracy and RT served as the dependent variables in separate models. Each model included fixed effects of BDI-II, DERS total score, STAI-State (STAI-1), and STAI-Trait (STAI-2), with a random intercept for participant ID to account for repeated observations.

2.5.2. *Subjective affective responses to emotional video*

After each video was objectively classified, participants were asked to provide a subjective rating, indicating a scale from zero (sad) to nine (happy) about how the video made them feel. The mean rating for each condition was calculated and included in a LMM to assess differences between groups.

$$\text{model 3} \leftarrow \text{lmer}(\text{mean\_rating} \sim \text{task condition*group} + \text{age} + \text{sex} + (1|\text{ID}))$$

2.5.3. *Self-reported task difficulty*

Post-task, participants rated their own task performance via a questionnaire (Table S1, Fig. S2). Statistical differences between groups were analyzed within the questions: "How difficult was the objective assessment of the videos for you (based on sad, neutral, happy)?" and "How difficult was the subjective assessment of the videos for you? (from sad to happy)" using an LMM.

$$\text{model4} \leftarrow \text{lmer}(\text{response} \sim \text{question*group} + \text{age} + \text{sex} + (1|\text{ID}))$$

2.6. *fMRI data preprocessing and analysis*

Participants were placed with the EEG cap in a 3 T MR scanner (Siemens MAGNETOM Prisma®, Siemens Medical Systems, Germany). A T1-weighted sequence (magnetization-prepared rapid acquisition gradient echo image, MPRAGE) was acquired

(256× 256 matrix, TR = 1900 msec, TE = 2980 msec, FA = 9°, 176 slices, 1 mm slice thickness, acquisition time = 4.18 min). During the task, fMRI images were collected using a standard 20-channel head coil (EPI: 64 × 64 matrix, TR = 2000 msec, TE = 28 msec, FA = 77°, 34 slices, voxel size: 3.1 × 3.1 × 3.1 mm^3, spacing between slices: 25 %, 3.1 mm slice thickness, GRAPPA acceleration factor 2). Total scan time was 12 min, assessing 350 images. After the task, a gradient echo (GRE) measurement was performed to acquire phase and magnitude field maps (TE1 = 4.87 msec, TR = 526 msec, FA = 60°, 59 slices, slice thickness = 3 mm). Detailed MRI parameters and acquisition settings are detailed in the Supplements. Data preprocessing used SPM12 (Ashburner et al., 2021), excluding the first three volumes of each run to avoid artifacts. A voxel displacement map (VDM) was generated using echo times of 4.87 and 7.33 msec, along with the template image for brain mask T1. nii from the SPM toolbox's FieldMap, and phase and magnitude field maps obtained during gradient echo (GRE) measurement. This pre-calculated VDM was employed for distortion correction during the realignment phase, where images from the time series were aligned using the first image as a reference. Functional images were co-registered with corresponding individual anatomical images and then normalized to the Montreal Neurological Institute (MNI) standard space using normalization parameters and the tissue probability map (TPM.nii) from SPM, resampling all time-series images to a voxel size of 2 × 2 × 2 mm^3. Subsequently, images were smoothed using an isotropic Gaussian kernel of 6 mm full-width-at-half-maximum and high-pass filtered with a 128 sec cut-off to preserve Blood Oxygen Level Dependent signal frequencies.

Movement parameters were modeled using six parameters (translation in *x*, *y*, *z*, and rotation around *x* (pitch), *y* (roll), *z* (yaw)). A general linear model (GLM) was fitted to analyze the functional scans from each participant.

2.6.1. *Neural effects of emotional congruency and incongruency*

First-level GLMs were specified in SPM12 with four task regressors (happy_happy, happy_sad, sad_sad, sad_happy) and the six realignment parameters as nuisance regressors. Onsets and durations were derived from behavioral logfiles; primer duration was fixed at 16 msec and video durations were defined from video onset to response. Contrast images from the four primary conditions were entered into a whole brain second-level 2 × 2 × 2 full-factorial model (video emotion × primer emotion × group) using video and primer emotion as within-subject factors and group as between-subject factor. Age and sex were included as covariates of no interest.

2.6.2. *Reaction Time Effect on Neural Responses*

To address the potential confounding influence of psychomotor slowing on neural activation patterns, two additional second-level analyses were conducted. First, the full factorial model was re-estimated including condition-specific mean reaction time as an additional covariate of no interest, modeled as a single regressor across all subjects (along with age and sex). Second, a whole-brain multiple regression analysis was conducted for each stimulus condition separately, with condition-specific mean RT as the primary predictor and group, age, and sex as nuisance regressors (see Supplements "Reaction Time Effect on Neural Responses").

2.6.3. *Medication and depression severity effect on neural responses*

To examine neural responses to emotional face stimuli specifically within the patient group, a separate second-level whole-brain analysis was conducted for the MDD subsample. A 2 × 2 full factorial design was specified with two within-subject factors: primer emotion (happy, sad) and target emotion (happy, sad), yielding four conditions: happy–happy, happy–sad, sad–sad, and sad–happy. For each subject, the corresponding first-level contrast images were entered into the model. Patient-specific covariates (age, BDI-II depression score, and antidepressant medication status (binary)) were included in the model. Age served as nuisance covariates. BDI-II score and antidepressant status were included as covariates of interest to examine whether depression severity and antidepressant use modulated neural activity. Effects of both covariates were tested via *t*-contrasts.

All results were adjusted for multiple comparisons using a family-wise error (FWE) cluster correction at $p < .05$.

2.7. *Speech assessment and processing*

Before the simultaneous EEG-fMRI measurement, participants were instructed to narrate a positive and negative event from their lives, a method previously employed in studies to evoke emotional responses in speech (König et al., 2019, 2021). The participants' responses were captured using a tablet's built-in microphone. Speech feature extraction was performed using Python 3.9, utilizing the proprietary speech processing library "Sigma" V17.0.0 (ki:elements GmbH, Saarbrücken, Germany). Speech features were extracted from positive and negative storytelling conducted outside the MRI scanner (Menne et al., 2024) and are related to frequency, energy, spectral balance, temporal aspects, lexical richness, sentiment, word types, and syntactic complexity within positive and negative storytelling (Table S2).

2.8. *Emotion regulation and speech feature association moderated by group*

Regression analyses using Ordinary Least Squares regression models of the *statmodels* library in Python (Seabold & Perktold, 2010) were conducted to explore the relationship between speech features (duration, loudness, pause metrics, word frequency, word count, and emotional tone ratios) and questionnaire scores (CERQ, BVAQ, BDI-II, STAI 1/2, DERS) for positive and negative storytelling contexts (duration, loudness, total pause duration, mean pause duration, number of pauses, word frequency, word count, and the ratios of negative, neutral, and positive sentences). Group status served as a moderator to assess how these relationships differ between MDD and HC groups. For each combination of speech feature ($n = 20$; 10 per storytelling condition) and questionnaire measure ($n = 20$; total scores and subscales), a separate moderated regression model was estimated including group as a moderator (speech feature ~ questionnaire + group + questionnaire × group). This resulted in

400 interaction tests. To control for multiple comparisons across all interaction terms, *p*-values were adjusted using the Benjamini–Hochberg false discovery rate procedure (FDR-adjusted *p*-values >.05). Positive interaction coefficients indicate stronger associations in the MDD group, whereas negative coefficients suggest weaker associations compared to HC.

3. Results

3.1. *Behavioral effects of subliminal priming during emotional video processing*

3.1.1. *Reaction time and accuracy during emotional video classification*

3.1.1.1. Reaction time. A main effect of group, task condition, and age on the mean reaction time was found (Table 2, Fig. 2).

Post hoc analyses showed that mean RT is higher in MDD compared to HC ($t_{113} = 2.522$, $p = .013$, Fig. 2A). With higher age, mean reaction time increased (person's rho = .279, $p < .001$, Fig. 2B). Mean RT was lower in trials with happy primer presentation (happy happy − happy sad: $t_{347} = -9.253$, $p < .001$; happy happy − sad sad: $t_{349} = -3.446$, $p < .004$; happy sad − sad happy: $t_{349} = 7.429$, $p < .001$; happy sad −sad sad: $t_{349} = 5.820$, $p < .001$, Fig. 2C). The mean RT during a video representing a happy situation was not affected by happy or sad primer presentation (happy happy − sad happy: $t_{349} = -1.781$, $p = .454$, Fig. 2C). RT was not significantly different during sad primer presentation in both, happy and sad video presentation (sad happy − sad sad: $t_{349} = -1.653$, $p = .595$).

3.1.1.2. Accuracy. A main effect of task conditions on the mean accuracy was found as well as an interaction effect between the group and the task condition (Table 3).

Accuracy was significantly lower in trials with a sad primer, compared to trials with happy primer presentation during happy video presentation (happy happy − sad happy: $t_{348} = 3.367$, $p = .005$, Fig. 2D). Sad video with happy primer presentation led to lower accuracy compared to congruent happy video/primer presentation (happy happy − happy sad: $t_{348} = 4.146$, $p < .001$). Condition × group interaction show that this effect is only stable in HC group and not in MDD (HC: happy happy − happy sad: $t_{348} = 3.813$, $p = .005$; MDD: happy happy-happy sad: $t_{348} = 2.087$, $p > .999$). MDD show reduced accuracy during sad primer presentation within a happy video presentation compared to happy primer presentation during happy video presentation (MDD: happy happy − sad happy: $t_{348} = 3.318$, $p = .028$), an effect absence in the HC group, Fig. 2E). Between groups, HC show higher accuracy in happy primer trials compared to MDD in sad primer trials during happy video presentation (HC happy happy − MDD sad happy: $t_{348} = 3.259$, $p = .036$, Fig. 2E). All other post hoc tests did not show significant differences. For all post hoc results, see Table S3.

None of the self-report measures were significantly associated with RT (Table S4). Accuracy was negatively associated with BDI-II ($t_{106} = -2.08$, $p = .040$), indicating that higher depressive symptom severity was associated with lower task accuracy. DERS, STAI-State, and STAI-Trait were not significantly associated with accuracy (all $p > .47$, Table S4).

3.1.2. *Subjective affective responses to emotional video*

HC rated the presented videos more positively compared to MDD ($t_{114} = 3.49$, $p < .001$). Age and sex had no effect on the subjective video rating (Table S5). See Tables S5 and S6, Fig. S3 for all results.

3.1.3. *Self-reported task difficulty*

MDD reported significantly more difficulties rating the presented videos in both objective and subjective rating ($t_{76} = 3.69$, $p < .001$). Age and sex had no effect on the own performance rating (Table S8). See Supplements for all results.

3.2. *fMRI results*

No interaction effect between group and task condition was found.

3.2.1. *Group differences in neural responses during emotional video processing*

The factorial design analyzing interactions between groups, primer emotion, and video emotion indicated a significant main group effect. Post hoc comparisons revealed that MDD exhibited increased activity exclusively in the right hemisphere in the inferior and middle occipital gyrus (IOG, MOG) and the inferior temporal gyrus (ITG) compared to HC ($k = 16$, $x = 46$, $y = -76$, $z = -4$, $p_{FWE} < .05$) (Fig. 3A, Table S9). None of the tested group interactions with primer or target emotion reached significance. Mean contrast estimates (first-level parameter estimates) were extracted from the cluster exhibiting a significant MDD > HC (Fig. 3B). Welch's *t*-tests (HC versus MDD per condition), were performed and Bonferroni-corrected four comparisons (corrected $\alpha = .0125$, Table S9). The observed group difference in BOLD signal was not qualified by a significant interaction with task condition, and should therefore not be interpreted as condition-specific neural processing differences between groups.

Table 2 – Effects on mean reaction time. Type III analysis of variance table with Kenward-Roger's method (model 1).

	Sum Sq	Mean Sq	df_{Num}	*df*	F	*p*
Condition	.95	.32	3	348.31	32.13	<.001[c]
Group	.06	.06	1	112.87	6.36	.013[b]
Age	.16	.16	1	113.09	16.20	<.001[c]
Sex	.02	.02	1	112.85	1.76	.187
Condition*Group	.03	.01	3	348.32	.92	.429

Note. Sum Sq, sum of squares; Mean Sq, mean of squares; df, degrees of freedom; dfNum, Number of df; a, $p < .05$; *b*, $p < .01$; c, $p < .001$.

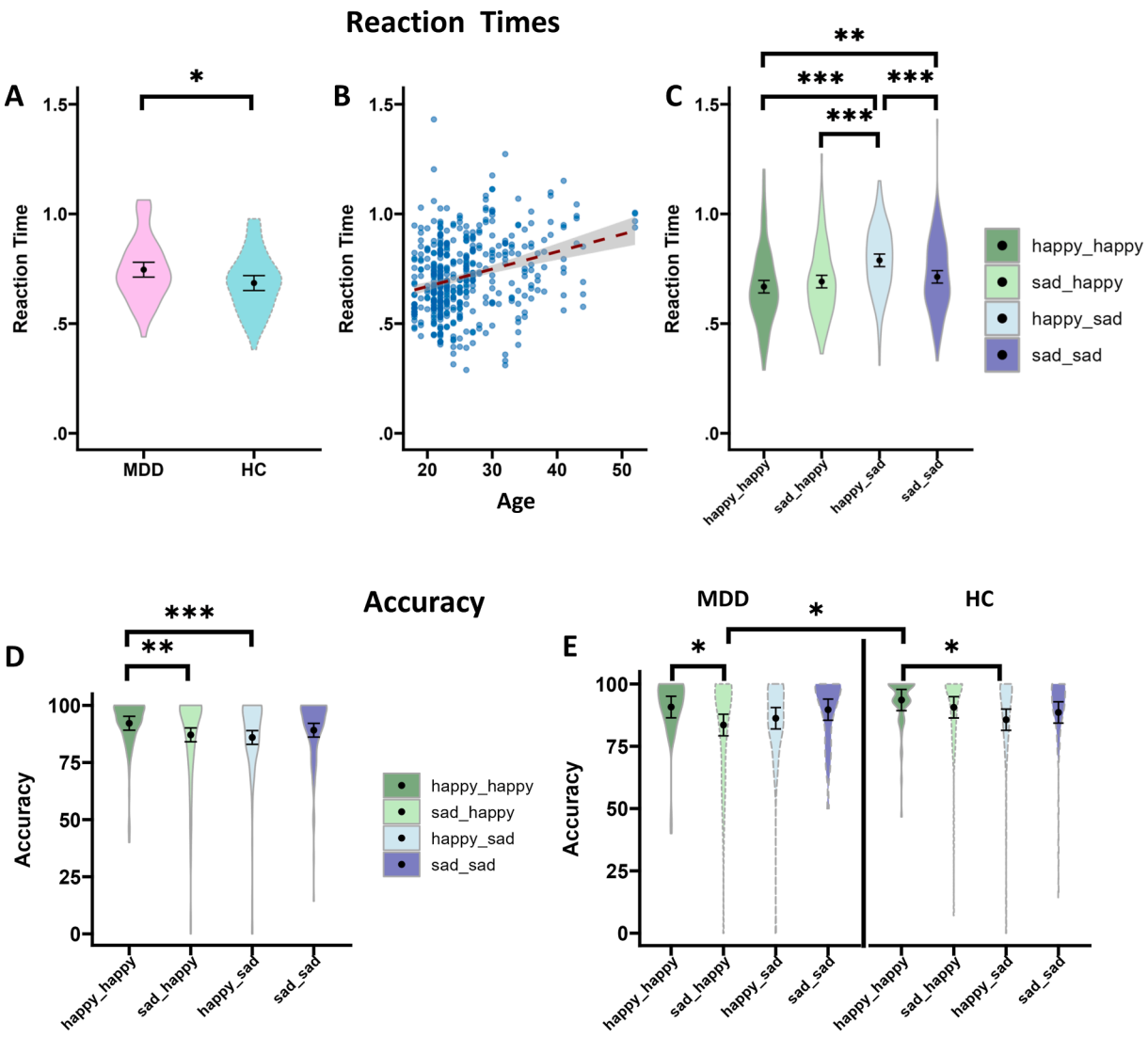

Fig. 2 – Effect plots of significant factors within the linear mixed model using mean RT values as dependent variable (A, B, C) and using mean accuracy as dependent variable (C, D). Significant main effects were group (A), age (B) and condition (C, with *p*-value adjustment for 4 tests). Effect plots of significant factors within the linear mixed model using mean accuracy as dependent variable (C, D). Significant main effects were the task conditions (happy/sad primer × happy/sad video) with *p*-value adjustment for 4 tests (C). Interaction effect between conditions and group with *p*-value adjustment for 28 tests (E). Legend: "happy happy", happy primer and happy video; "sad happy", sad primer and happy video; "happy sad", happy primer, sad video; "sad sad", sad primer and happy video; HC, healthy controls; MDD, major depressive disorder; HC: $n = 58$, MDD: $n = 59$; *p*-value adjustment was done using the Bonferroni method within the emmeans function in R. *, $p < .05$; **, $p < .01$; ***, $p < .001$.

Table 3 – Effects on mean accuracy. Type III analysis of variance table with Kenward-Roger's method (model 2).

	Sum Sq	Mean Sq	df_{Num}	*df*	F	*p*
Condition	2608.21	869.40	3	348.58	6.60	<.001[c]
Group	91.75	91.75	1	112.79	.70	.406
Age	109.52	109.52	1	112.96	.83	.364
Sex	202.99	202.99	1	112.76	1.54	.217
Condition*Group	1247.67	415.89	3	348.58	3.16	.025[a]

Note. Sum Sq, sum of squares; Mean Sq, mean of squares; df, degrees of freedom; df_{Num}, Number of df; a, $p < .05$; *b*, $p < .01$; c, $p < .001$.

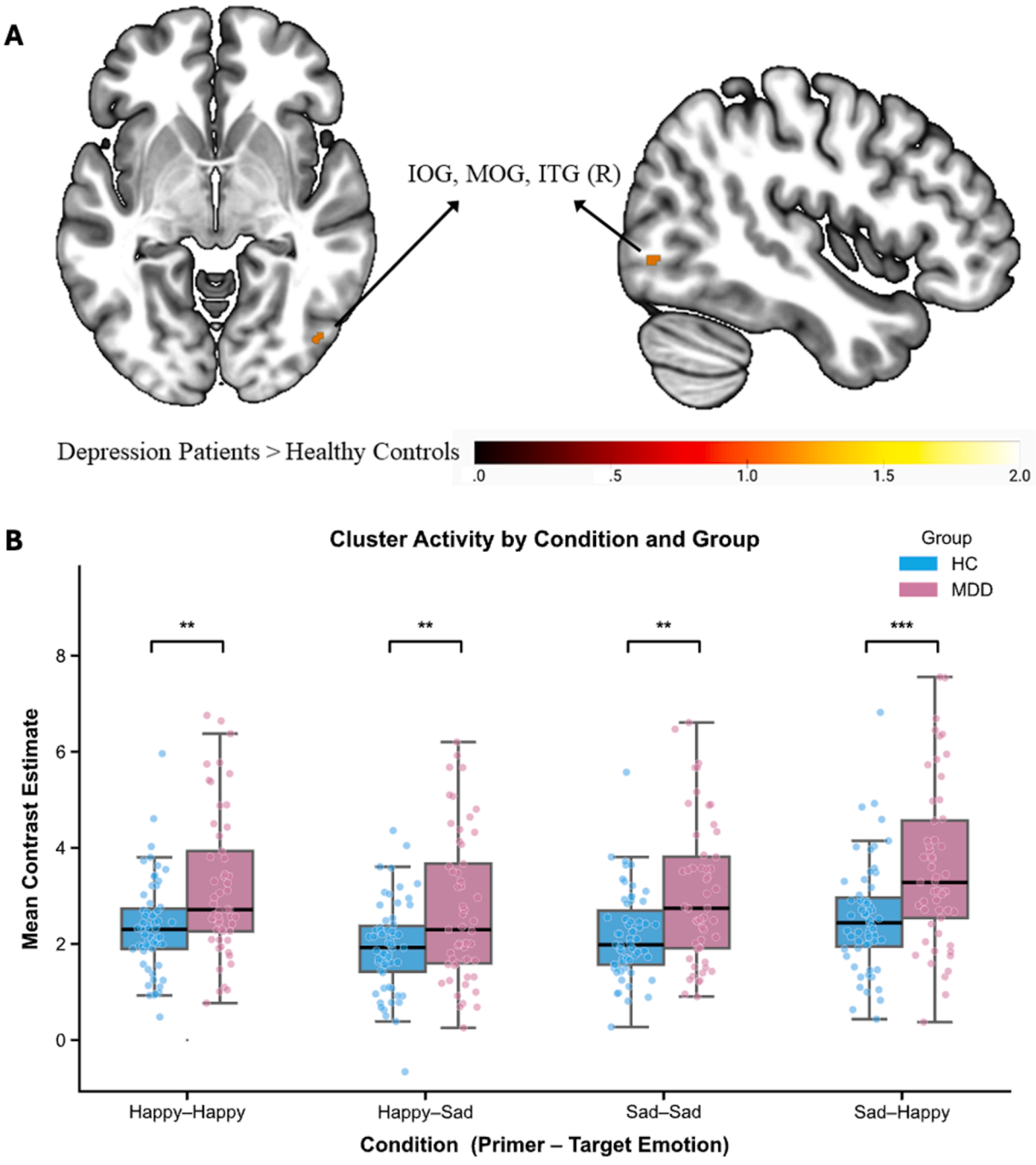

Fig. 3 – A: Statistical parametric map showing the post hoc effect of higher BOLD responses of patients with depression compared to healthy controls including age and sex as covariates ($p < .05$, FWE-corrected). IOG = inferior occipital gyrus, MOG = middle occipital gyrus, ITG = inferior temporal gyrus. The hemisphere side is indicated with "R" for right. B: Boxplots show mean contrast estimates (first-level parameter estimates) extracted from the cluster exhibiting a significant MDD > HC effect in the 2 × 2 × 2 full factorial design (primer emotion × target emotion × group). Each dot represents one participant. Significance brackets reflect independent-samples Welch's t-tests (HC versus MDD per condition), Healthy controls = HC, blue; patients with major depressive disorder = MDD, pink. Bonferroni-corrected for four comparisons (corrected $\alpha = .0125$). All results are reported in the Supplements. *$p < .0125$; **$p < .0025$; ***$p < .00025$.

3.2.2. *Neural effects of emotional congruency and incongruency*

A significant interaction effect between primer and video emotion was found in pooling data from both groups (MDD and HC). Post hoc comparisons between happy and sad primer presentations during happy and sad video presentations are reported below.

3.2.2.1. HAPPY VIDEO CONDITIONS. Congruent conditions during happy video presentation (with happy primer) led to increased brain activity in occipital regions [bilateral lingual gyrus (LING), bilateral calcarine fissure and surrounding cortex (CAL), bilateral superior occipital gyrus (SOG), bilateral cuneus (CUN), Fig. 4, red].

Incongruent conditions during happy video presentation (with sad primer) resulted in higher brain activity frontal regions [bilateral supplementary motor area (SMA), bilateral superior frontal gyrus (SFG), left SFG medial (SFGmedial), bilateral inferior frontal gyrus opercular part (IFGoperc), left IFG triangular part (IFGtriang), left middle frontal gyrus (MFG), bilateral IFG pars orbitalis], parietal regions [left precentral gyrus (PreCG), left postcentral gyrus (PoCG), left inferior parietal gyrus (IPG), left IPG excluding supramarginal and angular gyri, bilateral superior parietal gyrus (SPG), right angular gyrus (ANG), bilateral supramarginal gyrus (SMG)], and in temporal regions such as the bilateral superior temporal gyrus (STG) and bilateral middle temporal gyrus (MTG). Additionally, occipital regions such as the bilateral MOG, bilateral IOG, bilateral fusiform gyrus (FFG) and bilateral LING are higher activated. The bilateral middle cingulate and paracingulate gyri (MCC) and bilateral insula also showed higher brain activity during incongruent happy video trials. Apart from cortical brain regions, additional subcortical brain regions showed increased brain activity during incongruent happy video trials (e.g., bilateral putamen, bilateral caudate nucleus, left ventral anterior and lateral thalamus (tVA/tVL), left mediodorsal lateral parvocellular (tMDl) and the right lobule VI of cerebellar hemisphere (CER6) (Fig. 4, green). For all significant clusters see Table 4.

3.2.2.2. SAD VIDEO CONDITIONS. Congruent conditions during sad video presentation (with sad primer) led to increased brain

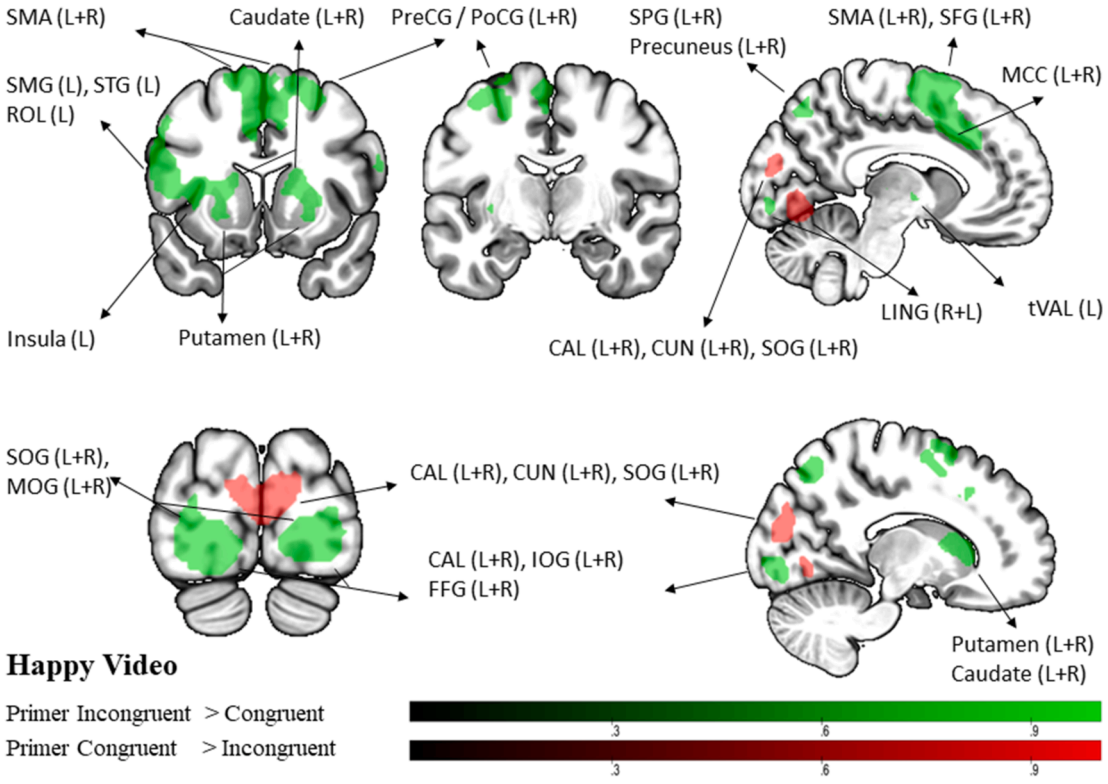

Fig. 4 – Statistical parametric map showing the post hoc effect of primer emotion and video emotion during happy video processing from the full factorial design calculated for each condition (happy/sad/primer × happy/sad video × group) including age and sex as covariates ($p < .05$, FWE-corrected). Incongruent primer (sad faces) > congruent primer (happy faces) is shown in green. Congruent primer > incongruent primer is shown in red. SMA = supplementary motor area, caudate = caudate nucleus, SPG = superior parietal gyrus, Pre/PostCG = pre/postcentral gyrus, SFG = superior frontal gyrus, SMG = supramarginal gyrus, STG = superior temporal gyrus, ROL = rolandic operculum, CAL = calcarine fissure and surrounding cortex, CUN = cuneus, SOG = superior occipital gyrus, LING = lingual gyrus, tVAL = MCC = middle cingulate & paracingulate gyri, FFG = fusiform gyrus, IOG = inferior occipital gyrus, MOG = middle occipital gyrus. The hemisphere side is indicated with "R" for right and "L" for left.

Table 4 – Emotion effect of full factorial analysis of primer emotion × video emotion × group after FWE correction ($p < .05$). Happy videos were subliminally primed with either happy or sad facial expressions.

Happy Video Primer Condition					
Happy PrimerVideo (Congruent) > Sad PrimerVideo (Incongruent)					
Abbreviation	Label	Cluster	% cluster	k	x,y,z in mm
LING L	Lingual gyrus L	1	18.86	1951	[-4;-78;-6]
CUN R	Cuneus R		17.38		
CAL R	Calcarine fissure and surrounding cortex R		14.56		
CAL L	Calcarine fissure and surrounding cortex L		12.66		
LING R	Lingual gyrus R		12.15		
Cuneus L	Cuneus L		9.94		
SOG L	Superior occipital gyrus L		2.31		
SOG R	Superior occipital gyrus R		2.15		
Sad primer video (incongruent) > happy PrimerVideo (congruent)					
Abbreviation	Label	Cluster	% Cluster	k	x,y,z in mm
SMA L	Supplementary motor area L	1	22.57	5729	[-4;0;66]
SMA R	Supplementary motor area R		14.78		
PreCG L	Precentral gyrus L		12.46		
PoCG L	Postcentral gyrus L		10.26		
SFG L	Superior frontal gyrus L		9.15		
IPG L	Inferior parietal gyrus L		6.34		
SFG R	Superior frontal gyrus R		5.92		
MCC R	Middle cingulate & paracingulate gyri R		4.38		
SFGmed L	Superior frontal gyrus, medial L		3.56		
MCC L	Middle cingulate & paracingulate gyri L		3.18		
IFGoperc L	Inferior frontal gyrus, opercular part L	2	26.22	1613	[-48;8;12]
Putamen L	Putamen L		17.73		
PreCG L	Precentral Gyrus L		15.87		
Insula L	Insula L		15.44		
Caudate L	Caudate nucleus L		9.67		
IFGtriang L	Inferior frontal gyrus, triangular part L		5.27		
ROL L	Rolandic operculum L		2.73		
MOG L	Middle occipital gyrus L	3	41.41	925	[-16;-92;-6]
IOG L	Inferior occipital gyrus L		22.92		
Lingual L	Lingual gyrus L		18.7		
Calcarine L	Calcarine fissure and surrounding cortex L		4.86		
FFG L	Fusiform gyrus L		4.22		
Lingual gyrus R	Lingual gyrus R	4	27.96	837	[22;-92;-4]
MOG R	Middle occipital gyrus R		22.34		
CAL R	Calcarine fissure and surrounding cortex R		19.95		
IOG R	Inferior occipital gyrus R		17.92		
FFG R	Fusiform gyrus R		4.42		
SOG R	Superior occipital gyrus R		3.46		
SPG L	Superior parietal gyrus L	5	65.38	699	[-20;-66;50]
PCUN L	Precuneus L		16.02		
MOG L	Middle occipital gyrus L		8.3		
SOG L	Superior occipital gyrus L		4.72		
IPG L	Inferior parietal gyrus, excluding supramarginal and angular gyri L		4.01		
Caudate R	Caudate nucleus R	6	51.92	572	[16;22;8]
PUT R	Lenticular nucleus, putamen R		38.64		
SMG L	Supramarginal gyrus L	7	56.64	535	[-50;-36;26]
STG L	Superior temporal gyrus L		24.11		
ROL L	Rolandic operculum L		10.28		
PoCG L	Postcentral gyrus L		3.93		
SPG R	Superior parietal gyrus R	8	44.81	395	[12;-70;54]
PCUN R	Precuneus R		36.2		
SOG R	Superior occipital gyrus R		11.39		
ANG R	Angular gyrus R		6.08		
STG R	Superior temporal gyrus R	7	56.13	212	[62;-34;20]
SMG R	Supramarginal gyrus R		43.87		
IPG R	Inferior parietal gyrus, excluding supramarginal and angular gyri R	8	48.89	45	[40;-38;42]
SMG R	Supramarginal gyrus R		37.78		
IFGtriang L	Inferior frontal gyrus, triangular part L	9	100	34	[-44;32;2]
MTG R	Middle temporal gyrus R		94.74	19	[52;-70;2]

Table 4 – (*continued*)

Happy Video Primer Condition					
Happy PrimerVideo (Congruent) > Sad PrimerVideo (Incongruent)					
Abbreviation	Label	Cluster	% cluster	k	x,y,z in mm
MOG R	Middle occipital gyrus R		5.26		
CER6 R	Lobule VI of cerebellar hemisphere R		100	5	[36;-56;-30]
IFGoperc R	Inferior frontal gyrus, opercular part R	10	79.17	24	[62;12;22]
PreCG R	Precentral gyrus R		20.83		
tVA L	Ventral anterior thalamus L		71.43	7	[-8;-8;-2]
MTG L	Middle temporal gyrus L	11	52.17	23	[-50;-70;2]
MOG L	Middle occipital gyrus L		47.83		
MFG L	Middle frontal gyrus L	12	80	20	[-48;26;32]
IFGtriang L	Inferior frontal gyrus, triangular part L		20		
SFG L	Superior frontal gyrus L	13	58.33	12	[-22;48;30]
MTG L	Middle frontal gyrus L		41.67		
Putamen L	Putamen L	14	50	8	[-34;-12;0]
tVL L	Ventral lateral thalamus L	15	85.71	7	[-10;-16;10]
tMDl L	Mediodorsal lateral parvocellular L		14.29		
Insula L	Insula L	16	66.67	6	[-30;28;4]
IFGtriang L	Inferior frontal gyrus, triangular part L		33.33		
Insula L	Insula L	17	80	5	[-32;26;-8]
IFGorb L	IFG pars orbitalis L		20		

Note. Clusters were labeled with AAL3 toolbox in SPM12. Clusters labeled with "outside" or smaller than $k < 5$ are not reported. Cluster labels containing less than 2% of the cluster are not reported. L, left hemisphere; R, right hemisphere.

activity in several frontal regions [bilateral SFG, as well as bilateral SFG medial (SFGmedial) and medial orbital (SFGorbital), left MFG and left anterior cingulate cortex pregenual (ACCpre)], parietal regions [right PoCG, bilateral precuneus, bilateral angular gyrus, bilateral SPG, bilateral], temporal regions [bilateral STG, bilateral MTG, bilateral FFG, left ITG] and occipital regions [bilateral CAL, bilateral LING, bilateral SOG, bilateral MOG, right cuneus]. Bilateral insula as well as the right ROL showed increased activity. In subcortical regions, the bilateral caudate nucleus, bilateral putamen, right pulvinar inferior (tPuI) and right hippocampus showed increased activity (Fig. 5, purple).

Incongruent conditions during sad video presentation (with happy primer) led to increased activity in several frontal regions [bilateral SMA, bilateral SFG, bilateral MCC, bilateral IFGoperc, bilateral IFGtriang, bilateral MFG, left SFGmedial, left SFGorbital and left ACCpre] as well as in parietal regions [left PoCG, bilateral PreCG, bilateral IPG excluding supramarginal and angular gyri, right ANG, bilateral SMG, bilateral paracentral lobule (PCL)] and temporal regions [bilateral STG, bilateral MTG, left ITG]. Occipital brain regions such as the bilateral IOG, bilateral MOG, bilateral LING, right CAL, right precuneus, right SPG, right SOG and the right cuneus were higher activated compared to congruent trials. Bilateral insula, bilateral MCC, and bilateral ROL showed higher activity as in incongruent trials. Bilateral insula, bilateral MCC, bilateral ROL showed increased activation in incongruent sad video trials compared to congruent trials. Increased brain activity was found in subcortical regions i.e., bilateral caudate, bilateral putamen, right tPUI, left tVL, right hippocampus and the right lobule VI of cerebellar hemisphere (CER6) (Fig. 5, blue) (Table 5 for all significant cluster).

3.2.3. *Reaction time effect on neural responses*

The whole-brain RT regression revealed no significant positive or negative correlations between RT and neural activation in any of the four conditions at $p_{FWE} < .05$ (cluster-corrected at $p < .05$). No RT-related activation was observed in occipital or temporal cortex in any condition, indicating that the occipital hyperactivation reported above is not attributable to individual differences in response speed.

3.2.4. *Medication and depression severity effect on neural responses*

A significant effect of BDI-II score was observed in the left Cerebellum VI (90% of cluster), extending into left Cerebellar Crus I ($k = 10$, $x = -32$, $y = -74$, $z = -22$, $p_{FWE} < .06$, Fig. S4A). BOLD activity did not differ significantly between task conditions in this cluster (Fig. S4B). Antidepressant medication status (binary covariate) yielded no significant clusters.

3.3. *Neurophysiological and cognitive assessment*

The groups did not differ significantly in cognitive questionnaire scores (WMS, Digit Span) or sex distribution. Participants with MDD exhibited higher scores on the BDI-II, BVAQ, STAI-I, STAI-II, the DERS total score, and all DERS subscales, as well as on the CERQ subscales Self-Blame, Rumination, and Catastrophizing. In contrast, healthy controls showed higher

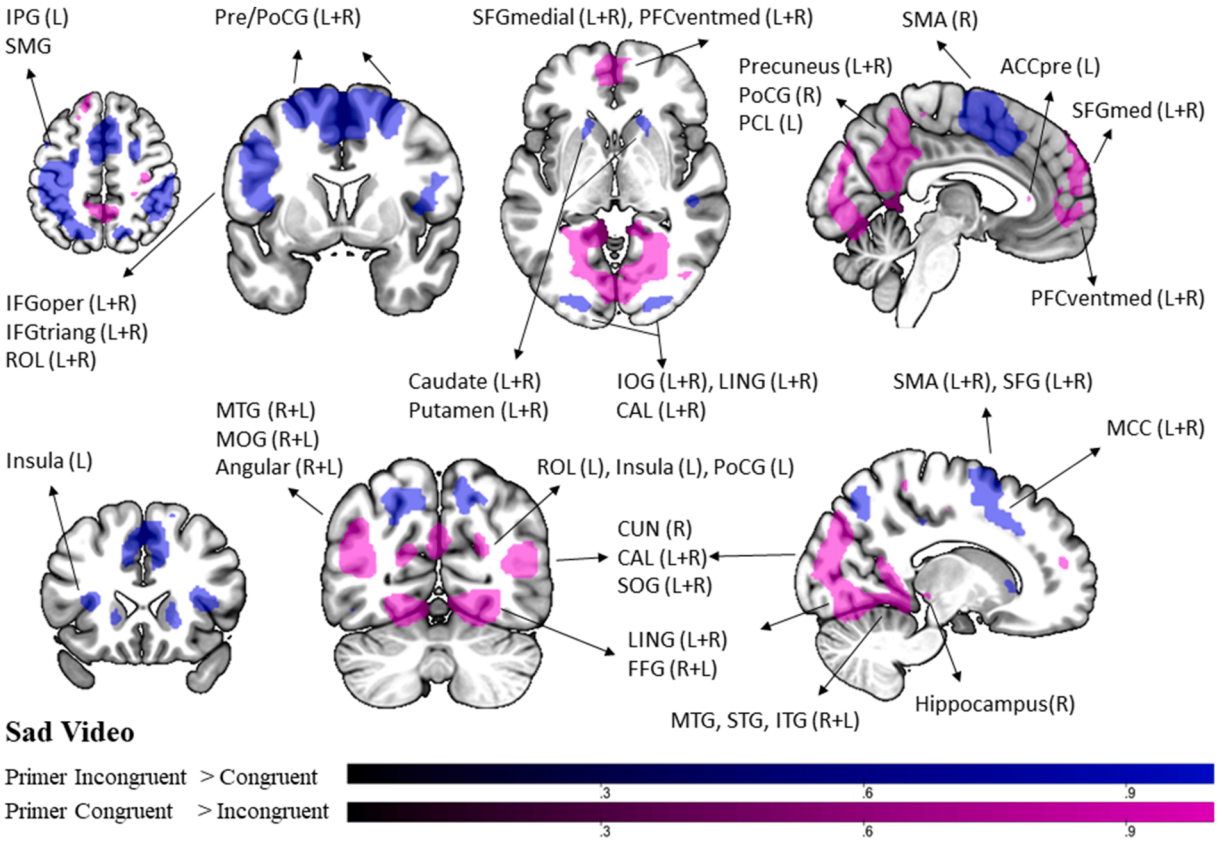

Fig. 5 – Statistical parametric map showing the post hoc effect of primer emotion and video emotion during sad video processing from the full factorial design calculated for each condition (happy/sad/primer × happy/sad video × group) including age and sex as covariates ($p < .05$, FWE-corrected). Incongruent primer (happy faces) > congruent primer (sad faces) is shown in blue. Congruent primer > incongruent primer is shown in purple. IPG = inferior parietal gyrus, excluding supramarginal and angular gyri, SMG = supramarginal gyrus, IFGoper = inferior frontal gyrus (opercular part) IFGtriang = inferior frontal gyrus (triangular part), ROL = rolandic operculum, Pre/PostCG = pre/postcentral gyrus, SFGmedial = superior frontal gyrus medial, PFCventmed = superior frontal gyrus (medial orbital), PCL = paracentral lobule, ACCpre = anterior cingulate cortex (pregenual), MTG = middle temporal gyrus, angular = angular gyrus, caudate = caudate nucleus, STG = superior temporal gyrus, ITG = inferior temporal gyrus, SMA = supplementary motor area, SFG = superior frontal gyrus, CAL = calcarine fissure and surrounding cortex, CUN = cuneus, LING = lingual gyrus, MCC = middle cingulate & paracingulate gyri, FFG = fusiform gyrus, IOG = inferior occipital gyrus, MOG = middle occipital gyrus. The hemisphere side is indicated with "R" for right and "L" for left.

scores on the CERQ subscales Positive Refocusing, Refocusing on Planning, Positive Reappraisal, and Putting into Perspective. All results are corrected for multiple comparisons using Bonferroni correction (Table 1).

3.4. *Emotion regulation and speech feature association moderated by group*

Descriptive statistics of speech features for each group can be found in Table 6. Regression analysis using the group as moderator revealed no significant interactions between speech features and questionnaire results after correcting multiple comparisons.

4. Discussion

This study examined mood-congruent bias in major depressive disorder using a dynamic emotional video paradigm combined with subliminal facial priming and multimodal assessment. Subliminal emotional primes influenced behavioral performance during emotional video processing in both patients and controls, indicating engagement of emotional conflict processing under unconscious conditions. Compared to healthy controls, individuals with MDD showed overall reduced behavioral performance and increased activation in right occipito-temporal regions, including the inferior and middle occipital

Table 5 – Emotion effect of full factorial analysis of primer emotion × video emotion × group after FWE correction ($p < .05$). Sad videos were subliminal primed with either happy or sad facial expressions.

Sad video condition					
Happy primer (incongruent) > Sad primer (congruent)					
Abbreviation	Label	Cluster	% Cluster	k	x,y,z in mm
PostCG L	Postcentral gyrus L		15.26	9539	[-38;-18;56]
SMA L	Supplementary motor area L		14.08		
IPG L	Inferior parietal gyrus, excluding supramarginal and angular gyri L		12.94		
PreCG L	Precentral gyrus L		11.1		
SMA R	Supplementary motor area R		10.05		
SFG	Superior frontal gyrus, dorsolateral L		7.82		
MCC R	Middle cingulate & paracingulate gyri R		3.16		
MCC L	Middle cingulate & paracingulate gyri L		2.11		
IPG R	Inferior parietal gyrus, excluding supramarginal and angular gyri R		33.73	2324	[46;-34;44]
SMG R	Supramarginal gyrus R		29.43		
PoCG R	Postcentral gyrus R		25.82		
ANG R	Angular gyrus R		2.19		
PreCG L	Precentral gyrus L		34.38	1620	[-52;8;18]
IFGoperc L	Inferior frontal gyrus, opercular part L		32.1		
INS L	Insula L		18.27		
IFGtriang L	Inferior frontal gyrus, triangular part L		6.98		
ROL L	Rolandic operculum L		6.23		
IFGoperc R	Inferior frontal gyrus, opercular part R		49.64	969	[56;10;24]
INS R	Insula R		18.37		
ROL R	Rolandic operculum R		10.22		
PreCG R	Precentral gyrus R		8.15		
IFGtriang R	Inferior frontal gyrus, triangular part R		7.64		
MFG R	Middle frontal gyrus R		92.18	550	[38;40;30]
SFG R	Superior frontal gyrus R		7.45		
IOG L	Inferior occipital gyrus L		49.48	289	[-26;-94;-4]
MOG L	Middle occipital gyrus L		41.87		
Lingual L	Lingual gyrus L		5.19		
IOG R	Inferior occipital gyrus R		43.69	222	[24;-92;-6]
Lingual R	Lingual gyrus R		24.77		
Calcarine R	Calcarine fissure and surrounding cortex R		20.27		
MOG R	Middle occipital gyrus R		9.91		
Precuneus R	Precuneus R		61.84	207	[12;-68;52]
SPG R	Superior parietal gyrus R		35.27		
SOG R	Superior occipital gyrus R		2.9		
Caudate R	Caudate nucleus R		76.69	133	[18;22;-2]
PUT R	Lenticular nucleus, putamen R		18.05		
MFG L	Middle frontal gyrus L		96.43	112	[-38;40;24]
IFGtriang L	Inferior frontal gyrus, triangular part L		2.68		
Caudate L	Caudate nucleus L		48.45	97	[-16;16;-2]
PUT L	Lenticular nucleus, Putamen L		40.21		
ITG L	Inferior temporal gyrus L		96.23	53	[-46;-60;-8]
IOG L	Inferior occipital gyrus L		1.89		
STG R	Superior temporal gyrus R		92.5	40	[50;-28;0]
MTG R	Middle temporal gyrus R		7.5		
MCC R	Middle cingulate & paracingulate gyri R		93.33	15	[12;-30;40]
MCC L	Middle cingulate & paracingulate gyri L	15	100	12	[8;-10;32]
Sad primer (congruent) > happy primer (incongruent)					
Abbreviation	Label	Cluster	% Cluster	k	x,y,z in mm
LING R	Lingual gyrus R	1	9.81	12,155	[16;-86;18]
LING L	Lingual gyrus L		9.72		
PCUN L	Precuneus L		8.69		
PCUN R	Precuneus R		7.17		
CUN R	Cuneus R		6.18		
Calcarine L	Calcarine fissure and surrounding cortex L		5.95		
FFG R	Fusiform gyrus R		4.8		
CAL R	Calcarine fissure and surrounding cortex R		4.65		

(*continued on next page*)

Table 5 – (*continued*)

Sad video condition					
Happy primer (incongruent) > Sad primer (congruent)					
SOG R	Superior occipital gyrus R		4.16		
MTG R	Middle temporal gyrus R		3.27		
SOG L	Superior occipital gyrus L		2.89		
PoCG R	Postcentral gyrus R		2.35		
FFG L	Fusiform gyrus L		2.29		
SFGmedial L	Superior frontal gyrus, medial L	2	41.19	1107	[-4;62;-2]
SFGmedial R	Superior frontal gyrus, medial R		26.29		
PFCventmed L	Superior frontal gyrus, medial orbital L		12.2		
ACCpre L	Anterior cingulate cortex, pregenual L		8.58		
PFCventmed R	Superior frontal gyrus, medial orbital R		8.04		
MTG L	Middle temporal gyrus L	3	36.84	874	[-40;-66;14]
ANG L	Angular gyrus L		28.72		
MOG L	Middle occipital gyrus L		20.25		
MTG R	Middle temporal gyrus R	4	69.23	169	[54;-8;-18]
STG R	Superior temporal gyrus R		14.79		
SFG L	Superior frontal gyrus L	5	94.12	102	[-14;48;48]
SFGmedial L	Superior frontal gyrus medial L		1.96		
MTG L	Middle temporal gyrus L	6	96.36	55	[-60;-8;-18]
STG L	Superior temporal gyrus L		3.64		
SMA R	Supplementary motor area R	7	97.83	46	[6;-22;64]
PCL L	Paracentral lobule L		2.17		
SFG L	Superior frontal gyrus L	8	97.22	36	[-20;26;44]
MFG L	Middle frontal gyrus L		2.78		
ROL R	Rolandic operculum R	9	30.3	33	[40;-16;24]
INS R	Insula R		21.21		
CUN L	Caudate nucleus L	10	47.06	17	[-20;-18;24]
INS R	Insula R	11	33.33	15	[36;-28;24]
ROL R	Rolandic operculum R		20		
tPuI R	Pulvinar inferior R	12	12.5	8	[14;-28;-4]
PCL L	Paracentral lobule L	13	75	8	[-4;-34;58]
PCUN L	Precuneus L		25		
IFGorb R	IFG pars orbitalis R	14	100	6	[34;32;-12]
tPuI R	Pulvinar inferior R	15	33.33	6	[22;-30;4]
HIP R	Hippocampus R	16	66.67	6	[42;-18;-14]

Note. Clusters were labeled with AAL3 toolbox in SPM12. Clusters labeled with "outside" or smaller than $k < 5$ are not reported. Cluster labels containing less than 2% of the cluster are not reported. L, left hemisphere; R, right hemisphere.

gyri, suggesting greater perceptual and attentional demands during emotional processing. These findings indicate that mood-congruent biases in mood disorders in depression during dynamic emotional contexts can be expressed as reduced processing efficiency accompanied by increased neural recruitment, rather than as emotion-specific neural modulation.

4.1. *Increased cognitive-perceptual demands during emotional video processing in MDD*

In dynamic settings with emotional cues, congruent video content and subliminal primes enhanced detection speed and accuracy. Over all participants, distinct patterns of brain activity were associated with congruent and incongruent emotional conditions during video presentations. Congruent conditions, regardless of emotion, activated regions involved in visual and emotional processing (lingual gyrus, calcarine fissure, and SOG). This is consistent with previous findings suggesting a strong involvement of these areas in processing emotionally salient visual stimuli (Pessoa et al., 2002; Vuilleumier & Pourtois, 2007). Activation overlaps in congruent conditions for both happy and sad videos revealed significant visual area activation, indicating a robust visual response to emotionally congruent stimuli. This activation pattern aligns with behavioral data, showing shorter and more accurate response times in congruent trials, especially in HC.

In contrast, incongruent conditions engaged additional motor and frontal regions (SMA, precentral and postcentral gyri, frontal gyri), indicative of increased cognitive and motor planning needed to process mismatched stimuli (Cao et al., 2018; Müller et al., 2011). This aligns with cognitive dissonance theories, where conflicting inputs demand higher-order processing efforts (Fitzgerald et al., 2008; Harmon-Jones & Mills, 2019). The recruitment of additional cognitive and motor regions may indicate an increased effort to process and resolve the incongruent information. Notably, the dorsal ACC was crucial in tasks requiring automatic response inhibition, in order to perform in a task (as it is needed in backward mask tasks) (Etkin et al., 2011; Fang et al., 2022; Mitterschiffthaler et al., 2007; Nee et al., 2007). In this study, the middle cingulate and paracingulate gyrus were specifically activated during mismatch processing. Additionally, activation in the insula suggests increased demand for response selection, while activation in the IFG indicates a heightened

Table 6 – Descriptive statistics of speech features for each HC and MDD.

Item	Mean	SD	Mean	SD
Positive story	MD		HC	
Duration	38.114	31.514	19.961	13.759
Loudness	−48.891	4.950	−57.158	8.957
Pause durations (seconds)	.305	.392	.286	.279
Number of pauses	69.875	59.246	42.022	32.949
Word frequency	4.773	.254	4.818	.340
Word count	92.104	89.802	49.609	34.726
Negative sentence ratio	.103	.157	.068	.185
Neutral sentence ratio	.461	.316	.476	.346
Positive sentence ratio	.436	.290	.457	.347
Negative story				
Duration	73.659	85.248	26.017	18.010
Loudness	−49.701	5.454	−59.463	10.882
Pause durations (seconds)	.351	.361	.285	.122
Number of pauses	120.083	126.350	53.957	44.357
Word frequency	4.799	.152	4.764	.255
Word count	166.708	191.492	62.022	46.300
Negative sentence ratio	.126	.185	.199	.250
Neutral sentence ratio	.336	.224	.481	.273
Positive sentence ratio	.538	.271	.320	.236

Note. HC, healthy control; MDD, major depressive disorder.

need for conflict resolution, particularly in managing emotionally incongruent stimuli (Nee et al., 2007).

The absence of a significant group-by-condition interaction suggests that this increased occipito-temporal engagement reflects a general difference in processing emotional video content in MDD rather than a condition-specific modulation by congruency. Compared to HC, MDD participants displayed pronounced brain activity in the right hemisphere (IOG, MOG and ITG), areas known for their role in visual and emotional processing suggesting that patients may recruit additional neural resources to process emotionally salient stimuli (Du et al., 2023; Im et al., 2021). Notably, the right MOG and ITG also showed increased activation during specific task conditions, particularly incongruent conditions (i.e., incongruent happy video and sad primer conditions). This overlap could suggest that MDD might experience greater difficulty, or at least require greater neural and attentional resources, to process incongruent emotional stimuli compared to controls. This could reflect an increased cognitive effort required to reconcile conflicting emotional information, which is more challenging for MDD but also for other disorders with cognitive effort deficits such as anxiety or schizophrenia. Similar findings have been reported in previous studies, where altered activation in occipital and temporal regions during emotion processing has been observed in MDD, reflecting disrupted visual and emotional integration (Fitzgerald et al., 2008; Leppänen, 2006; Li & Wang, 2021). Given the cross-sectional design, the present findings characterize processing during acute depression rather than establishing trait markers or predictors of treatment response. The observed occipito-temporal hyperactivation is therefore interpreted as a state-related increase in processing demands. The absence of a significant group × condition interaction at the neural level contrasts with our initial hypothesis of a valence-specific neural bias in MDD. We had expected differential modulation of limbic and prefrontal regions depending on emotional congruency. Instead, our data indicate a global increase in occipito-temporal recruitment across conditions. One possible explanation is that dynamic, naturalistic stimuli engage in complex perceptual and integrative processes. This complexity may overshadow subtle valence-specific effects typically detectable in more controlled paradigms using static cues. In naturalistic contexts, mood-congruent biases may manifest less as discrete neural selectivity for specific valences and more as a generalized reduction in processing efficiency when emotionally salient information must be integrated and evaluated (as represented in the reaction times). Possible cognitive and attentional deficits in depression were not only indicated by the reduced task performance, but also by patients reporting significantly more difficulties classifying the presented emotional context (own task performance rating). This is further supported by the association of lower accuracy with higher depressive symptom severity (BDI-II) across groups while other self-reported emotional measures did not show robust associations with behavioral outcomes. Reduced accuracy within the MDD group during sad-prime/happy-video trials relative to congruent happy trials suggests that this type of emotional mismatch places particular demands on cognitive resources in patients. This indicates that a mood congruent bias is present towards negative stimulus material on an unconscious level, disrupting happy video processing. This indicates a cognitive challenge, highlighted by possible diminished response inhibition and altered attentional control, especially with negative stimuli as it has been found in previous studies (De Raedt & Koster, 2010). Our findings further point toward a potential role of the cerebellum in depressive symptomatology. Within the MDD group, higher depression severity (BDI-II), was associated with increased BOLD signal in the left cerebellar region. Considering emerging evidence implicating the cerebellum in affective and cognitive processing (Schmahmann, 2019), these findings may reflect altered cerebellar contributions to emotion-related networks in individuals with more severe depressive symptoms. Importantly, the observed main effect of group on reaction time indicates generalized slowing in MDD, consistent with psychomotor retardation described in the literature (Rock et al., 2014; Snyder, 2013). However, speed performance in neurocognitive tests (digit span, WMS, TMT-A/B) did not differ between groups. Effects of reaction time differences between conditions and groups did not impact neural activation as well. The increased occipito-temporal activation observed in MDD may reflect heightened neural effort associated with reduced processing efficiency more broadly, rather than a mechanism specific to emotional conflict per se. Distinguishing these cognitive influences from emotional reactions requires further study, potentially examining differential neural activation in circuits related to cognitive control and emotional processing.

Overall, the findings indicate that MDD experience increased difficulty in processing emotional stimuli and managing emotionally incongruent presentations, suggesting a generalized elevation in cognitive load during emotional mismatches rather than an emotion-specific deficit. This is in line with previous studies linking MDD with enhanced cognitive strain in the presence of conflicting emotional cues (Alders et al., 2019; Wagner et al., 2006) as well as reported

deficits in emotional discrimination and heightened susceptibility to emotional interference (Disner et al., 2011; Gotlib & Joormann, 2010) which have been repatriated to slowed cognitive processing and impaired attention (Rock et al., 2014; Snyder, 2013).

4.2. *Mood-congruent effects during unconscious emotional conflict*

Subliminal incongruent emotional cues disrupt video content processing, prompting the brain to engage additional regions for mismatch reconciliation and emotion interpretation. This neural activity is mirrored in behavioral outcomes as evidenced by increased reaction times when sad content is disrupted by happy primes, highlighting the prioritized processing of happy over sad expressions (Schräder et al., 2023; Svard et al., 2012). Generally, happy videos were processed faster and more accurately than sad ones, suggesting that positive emotional content facilitates quicker cognitive processing. This could be due to the association of positive stimuli with approach-related motivational systems, as previously reported in the literature (Isen, 2001).

Sad congruent conditions activate a broader network of visual and emotional processing areas compared to happy conditions, which primarily activate visual regions. This suggests greater cognitive effort is required to process negative stimuli. Accuracy declined under incongruent conditions, but the pattern of simple effects differed between groups: MDD showed reduced accuracy for sad-prime/happy-video trials relative to congruent happy trials, whereas HC showed reduced accuracy only for different video conditions irrespectively of the prime emotion. This indicates that individuals with MDD are particularly sensitive to this mismatch, which is in line with the expected bias towards negative emotional material. The subjective video ratings provide further evidence of the negative emotional processing bias in MDD, with participants generally rating the videos as more negative compared to HCs. This finding is consistent with the well-documented negative bias in emotional processing in depression (Beck, 1987; Disner et al., 2011; Gotlib et al., 2004; Schräder et al., 2024) and may reflect anhedonia, a core symptom of depression characterized by diminished ability to experience pleasure (Pizzagalli, 2014). This result is particularly important as it links the behavioral data on reaction time and accuracy with the subjective experience of the participants, providing a comprehensive view of how MDD affects both the cognitive and affective dimensions.

4.3. *Speech indicators of mood-congruent bias*

Speech production provides another lens through which the impact of MDD on emotional and cognitive processing can be understood. Depression has been consistently associated with changes in speech characteristics, such as prosody, speech rate, and loudness (Buyukdura et al., 2011; Cummins et al., 2015; Mundt et al., 2007, 2012). Verbal fluency, in particular, has been highlighted as a neuropsychological measure that can predict therapeutic outcomes and mood improvements (Alpert et al., 2001; Beblo et al., 1999; Cummins et al., 2015; König et al., 2019; Trichard et al., 1995). In a previous analysis of the same dataset, it was found that MDD show diminished verbal fluency during negative emotional contexts (Menne et al., 2024). Therefore, speech characteristics can serve as objective, scalable markers that complement traditional symptom-based assessments in MDD (Cummins et al., 2015; Mundt et al., 2007, 2012). Compared to healthy controls, individuals with MDD typically exhibit reduced prosodic variability (e.g., more monotonous intonation and lower intensity), slower speech rate, increased pausing, and diminished verbal fluency (Buyukdura et al., 2011; Cummins et al., 2015; Mundt et al., 2007, 2012). After correction for multiple comparisons, no robust group-moderated associations were observed in this study, suggesting that relationships between speech features and self-reported emotion regulation may be subtle, context-dependent, or not directly captured by cross-sectional questionnaire measures. These findings suggest that while speech features are indicative of broader cognitive and emotional challenges in MDD, their relationship to specific emotional regulation or psychopathological measures may be more nuanced or influenced by additional factors. Context-sensitive reductions in verbal fluency may provide incremental information about cognitive-affective vulnerability beyond self-report measures. At the same time, prior work emphasizes that speech-based markers are unlikely to function as standalone diagnostic tools and should instead be integrated into multimodal assessment frameworks to ensure adequate sensitivity and specificity (Alpert et al., 2001; Cummins et al., 2015). Further longitudinal and ecologically valid research is therefore required before routine clinical implementation can be recommended.

5. Conclusion, implications, and outlook

In summary, this study examined mood-congruent bias in MDD using a naturalistic emotional video paradigm combined with subliminal facial priming and multimodal assessment. Behaviorally, congruent prime-video pairings facilitated performance across participants, while individuals with MDD showed overall slower responses and more negative subjective ratings. Within-group analyses indicated reduced accuracy in MDD for sad-prime/happy-video trials relative to congruent happy trials while HC did not show this pattern, which supports the hypothesis of a mood congruent bias at unconscious level towards negative stimulus material. At the neural level, MDD was associated with increased right occipito-temporal activity, consistent with greater perceptual and attentional demands during emotional video processing, although a condition-specific group interactions in BOLD responses were not observed. Speech features collected outside the scanner did not show robust group-moderated associations with questionnaire measures after correction, suggesting that links between speech markers and self-reported emotion regulation in this sample may be subtle, indirect, or context-dependent. Together, these findings support the utility of dynamic, ecologically oriented paradigms for probing emotional conflict processing in depression and motivate longitudinal and task-locked multimodal work to clarify when these markers track symptom severity, treatment response, or clinically meaningful subtypes.

6. Limitations

Although the present sample size is comparatively large for an fMRI study in MDD, the findings derive from a single-site investigation in a predominantly young, German-speaking cohort. Replication across independent samples, imaging centers, and more diverse demographic backgrounds will be important to establish the robustness and generalizability of the observed behavioral interference effects and occipito-temporal activation patterns. The cross-sectional nature of the study prevents causal inferences; it is unclear whether emotional dysregulation leads to changes in speech patterns or vice versa. Given the cross-sectional design, the present findings characterize emotional processing during an acute depressive state rather than providing information about temporal stability or treatment-related change. A limitation of this study is the possibility that the medication status may normalize or otherwise alter BOLD signals, which could affect the interpretation of the resulting neural activity patterns. Effect of medication on reaction time, accuracy and neural data were therefore tested revealing no significant influences (see Supplements). Longitudinal studies could help clarify the directionality of these relationships. The reliance on self-reported measures might introduce bias, as individuals with depression might perceive and report their emotions and behaviors differently. Future research should also explore the role of other clinical characteristics (e.g., treatment history) in modulating these relationships. Understanding how these factors influence the correlation between speech features and psychological constructs could lead to more personalized and effective treatment strategies.

CRediT authorship contribution statement

Julia Schräder: Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Rebecca Sieberg:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Felix Menne:** Writing – review & editing, Methodology, Data curation. **Felix Dörr:** Writing – review & editing, Methodology, Data curation. **Johannes Tröger:** Supervision, Methodology. **Ute Habel:** Supervision, Funding acquisition. **Alexandra König:** Writing – review & editing, Supervision. **Lisa Wagels:** Writing – review & editing, Project administration, Conceptualization.

Patient consent statement

Informed consent was obtained from all individual participants included in the study.

Ethics approval

The study was approved by the internal ethics committee of the university hospital Aachen, Germany (Ethik-Kommission an der Medizinischen Fakultät der RWTH Aachen; vote number EK 045–19). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Data availability statement

The speech data generated and analyzed during the current study are not publicly available for privacy reasons. The code for speech feature extraction is not publicly available for intellectual property reasons but is available from the corresponding author upon reasonable request.

Declaration of generative AI use

Generative artificial intelligence tools were used to support language editing, improve clarity, and readability. Scientific content, data analyses, and interpretations were verified and approved by the authors. The authors take full responsibility for the integrity, accuracy, and originality of the work and confirm that the use of generative AI did not replace critical scholarly judgment or introduce unverified content.

Acknowledgements and funding statement

The authors express their gratitude to all participants. This research was supported by the Brain Imaging Facility at the Interdisciplinary Center for Clinical Research within the Faculty of Medicine, RWTH Aachen University, and the International Research Training Group (IRTG2150). Funding was provided by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under grant number 667892/JO 1453/2-1 and SFB-TRR 379-512007073.

Conflicts of interests

FM, FD, JT and AK are employees of ki:elements GmbH. JS, RS, LW and UH have no competing interests to declare.

Scientific transparency statement

DATA: Some raw and processed data supporting this research are publicly available, while some are subject to restrictions: https://github.com/JuliaSchraeder/SubliminalVideoPriming.git, https://rwth-aachen.sciebo.de/s/xHNMgH5sZzpSaZH.

CODE: All analysis code supporting this research is publicly available: https://github.com/JuliaSchraeder/SubliminalVideoPriming.git.

MATERIALS: Some study materials supporting this research are publicly available, while some are subject to restrictions: https://github.com/JuliaSchraeder/SubliminalVideoPriming.

DESIGN: This article reports, for all studies, how the author(s) determined all sample sizes, all data exclusions, all data inclusion and exclusion criteria, and whether inclusion and exclusion criteria were established prior to data analysis.

PRE-REGISTRATION: At least part of the study procedures was pre-registered in a time-stamped, institutional registry prior to the research being conducted: https://osf.io/yt6gr At least part of the analysis plans was pre-registered in a time-stamped, institutional registry prior to the research being conducted: https://osf.io/jv5h2 The analyses that were undertaken deviated from the preregistered analysis plans. All such deviations are fully disclosed in the manuscript.

For full details, see the *Scientific Transparency Report* in the supplementary data to the online version of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2026.05.015.

REFERENCES

Ack Baraly, K. T., Muyingo, L., Beaudoin, C., Karami, S., Langevin, M., & Davidson, P. S. (2020). Database of emotional videos from Ottawa (DEVO). *Collabra: Psychology, 6*(1).

Alders, G. L., Davis, A. D., MacQueen, G., Strother, S. C., Hassel, S., Zamyadi, M., Sharma, G. B., Arnott, S. R., Downar, J., & Harris, J. K. (2019). Reduced accuracy accompanied by reduced neural activity during the performance of an emotional conflict task by unmedicated patients with major depression: A CAN-BIND fMRI study. *Journal of Affective Disorders, 257*, 765–773.

Alpert, M., Pouget, E. R., & Silva, R. R. (2001). Reflections of depression in acoustic measures of the patient's speech. *Journal of Affective Disorders, 66*(1), 59–69. https://doi.org/10.1016/S0165-0327(00)00335-9

Arnone, D., McKie, S., Elliott, R., Thomas, E. J., Downey, D., Juhasz, G., Williams, S. R., Deakin, J. W., & Anderson, I. M. (2012). Increased amygdala responses to sad but not fearful faces in major depression: Relation to mood state and pharmacological treatment. *American Journal of Psychiatry, 169*(8), 841–850.

Ashburner, J., Barnes, G., Chen, C.-C., Daunizeau, J., Flandin, G., Friston, K., Gitelman, D., Glauche, V., Henson, R., Hutton, C., Jafarian, A., Kiebel, S., Kilner, J., Litvak, V., Mattout, J., Moran, R., Penny, W., Phillips, C., Razi, A., & Zeidman, P. (2021). *SPM12 manual*.

Aviezer, H., Ensenberg, N., & Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception. *Current Opinion in Psychology, Emotion, 17*, 47–54. https://doi.org/10.1016/j.copsyc.2017.06.006

Bates, D. (2007). *Linear mixed model implementation in lme4* (Vol. 15). University of Wisconsin.

Beblo, T., Baumann, B., Bogerts, B., Wallesch, C.-W., & Herrmann, M. (1999). Neuropsychological correlates of major depression: A short-term follow-up. *Cognitive Neuropsychiatry, 4*(4), 333–341. https://doi.org/10.1080/135468099395864

Beck, A. T. (1987). Cognitive models of depression. *Journal of Cognitive Psychotherapy, 1*, 5–37.

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). Beck depression inventory-II. *San Antonio, 78*(2), 490–498.

Beesdo-Baum, K., Zaudig, M., & Wittchen, H.-U. (2019). *SCID-5-CV Strukturiertes Klinisches Interview für DSM-5-Störungen–Klinische Version: Deutsche Bearbeitung des Structured Clinical Interview for DSM-5 Disorders–Clinician Version von Michael B. First, Janet BW Williams, Rhonda S. Karg, Robert L. Spitzer*. Hogrefe.

Besteher, B., Squarcina, L., Spalthoff, R., Bellani, M., Gaser, C., Brambilla, P., & Nenadić, I. (2019). Hippocampal volume as a putative marker of resilience or compensation to minor depressive symptoms in a nonclinical sample. *Frontiers in Psychiatry, 10*.

Bomfim, A. J. de L., Ribeiro, R. A., dos, S., & Chagas, M. H. N. (2019). Recognition of dynamic and static facial expressions of emotion among older adults with major depression. *Trends in Psychiatry and Psychotherapy, 41*, 159–166. https://doi.org/10.1590/2237-6089-2018-0054

Bracht, T., Linden, D., & Keedwell, P. (2015). A review of white matter microstructure alterations of pathways of the reward circuit in depression. *Journal of Affective Disorders, 187*, 45–53.

Buyukdura, J. S., McClintock, S. M., & Croarkin, P. E. (2011). Psychomotor retardation in depression: Biological underpinnings, measurement, and treatment. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 35*(2), 395–409. https://doi.org/10.1016/j.pnpbp.2010.10.019

Cao, L., Xu, J., Yang, X., Li, X., & Liu, B. (2018). Abstract representations of emotions perceived from the face, body, and whole-person expressions in the left postcentral gyrus. *Frontiers in Human Neuroscience, 12*, 419. https://doi.org/10.3389/fnhum.2018.00419

Courtney, C. G., Dawson, M. E., Schell, A. M., Iyer, A., & Parsons, T. D. (2010). Better than the real thing: Eliciting fear with moving and static computer-generated stimuli. *International Journal of Psychophysiology, 78*(2), 107–114. https://doi.org/10.1016/j.ijpsycho.2010.06.028

Cummins, N., Scherer, S., Krajewski, J., Schnieder, S., Epps, J., & Quatieri, T. F. (2015). A review of depression and suicide risk assessment using speech analysis. *Speech Communication, 71*, 10–49. https://doi.org/10.1016/j.specom.2015.03.004

Dan-Glauser, E. S., & Scherer, K. R. (2012). The difficulties in emotion regulation scale (DERS). *Swiss Journal of Psychology, 71*(1), 5–9. https://doi.org/10.1024/1421-0185/a000093.

De La Peña-Arteaga, V., Berruga-Sánchez, M., Steward, T., Martínez-Zalacaín, I., Goldberg, X., Wainsztein, A., Abulafia, C., Cardoner, N., Castro, M. N., Villarreal, M., Menchón, J. M., Guinjoan, S. M., & Soriano-Mas, C. (2021). An fMRI study of cognitive reappraisal in major depressive disorder and borderline personality disorder. *European Psychiatry, 64*(1), Article e56. https://doi.org/10.1192/j.eurpsy.2021.2231

De Raedt, R., & Koster, E. H. W. (2010). Understanding vulnerability for depression from a cognitive neuroscience perspective: A reappraisal of attentional factors and a new conceptual framework. *Cognitive, Affective and Behavioral Neuroscience, 10*(1), 50–70. https://doi.org/10.3758/CABN.10.1.50

Diener, C., Kuehner, C., Brusniak, W., Ubl, B., Wessa, M., & Flor, H. (2012). A meta-analysis of neurofunctional imaging studies of emotion and cognition in major depression. *NeuroImage, 61*(3), 677–685. https://doi.org/10.1016/j.neuroimage.2012.04.005

Disner, S. G., Beevers, C. G., Haigh, E. A., & Beck, A. T. (2011). Neural mechanisms of the cognitive model of depression. *Nature Reviews Neuroscience, 12*(8), 467–477.

Douglas, K. M., & Porter, R. J. (2009). Longitudinal assessment of neuropsychological function in major depression. *The Australian and New Zealand Journal of Psychiatry, 43*(12), 1105–1117. https://doi.org/10.3109/00048670903279887

Du, Y., Hua, L., Tian, S., Dai, Z., Xia, Y., Zhao, S., Zou, H., Wang, X., Sun, H., Zhou, H., Huang, Y., Yao, Z., & Lu, Q. (2023). Altered beta band spatial-temporal interactions during negative emotional processing in major depressive disorder: An MEG study. *Journal of Affective Disorders, 338*, 254–261. https://doi.org/10.1016/j.jad.2023.06.001

Duque, A., & Vázquez, C. (2015). Double attention bias for positive and negative emotional faces in clinical depression: Evidence from an eye-tracking study. *Journal of Behavior Therapy and Experimental Psychiatry, 46*, 107–114.

Ebner, N. C., Riediger, M., & Lindenberger, U. (2010). FACES—A database of facial expressions in young, middle-aged, and older women and men: Development and validation. *Behavior Research Methods, 42*(1), 351–362.

Elliott, R., Rubinsztein, J. S., Sahakian, B. J., & Dolan, R. J. (2002). The neural basis of mood-congruent processing biases in depression. *Archives of General Psychiatry, 59*(7), 597–604.

Enneking, V., Leehr, E. J., Dannlowski, U., & Redlich, R. (2020). Brain structural effects of treatments for depression and biomarkers of response: A systematic review of neuroimaging studies. *Psychological Medicine, 50*(2), 187–209. https://doi.org/10.1017/S0033291719003660

Esteban, O., Markiewicz, C. J., Blair, R. W., Moodie, C. A., Isik, A. I., Erramuzpe, A., Kent, J. D., Goncalves, M., DuPre, E., & Snyder, M. (2019). fMRIPrep: A robust preprocessing pipeline for functional MRI. *Nature Methods, 16*(1), 111–116.

Etkin, A., Egner, T., & Kalisch, R. (2011). Emotional processing in anterior cingulate and medial prefrontal cortex. *Trends in Cognitive Sciences, 15*(2), 85–93.

Everaert, J., Koster, E. H. W., & Derakshan, N. (2012). The combined cognitive bias hypothesis in depression. *Clinical Psychology Review, 32*(5), 413–424. https://doi.org/10.1016/j.cpr.2012.04.003

Falkai, P., Wittchen, H.-U., & Döpfner, M. (2018). *Diagnostisches und statistisches Manual psychischer Störungen DSM-5*. Hogrefe.

Fan, X., Mocchi, M., Pascuzzi, B., Xiao, J., Metzger, B. A., Mathura, R. K., Hacker, C., Adkinson, J. A., Bartoli, E., Elhassa, S., Watrous, A. J., Zhang, Y., Allawala, A., Pirtle, V., Mathew, S. J., Goodman, W., Pouratian, N., & Bijanki, K. R. (2024). Brain mechanisms underlying the emotion processing bias in treatment-resistant depression. *Nature Mental Health, 2*(5), 583–592. https://doi.org/10.1038/s44220-024-00238-w

Fang, Z., Lynn, E., Huc, M., Fogel, S., Knott, V. J., & Jaworska, N. (2022). Simultaneous EEG+ fMRI study of brain activity during an emotional Stroop task in individuals in remission from depression. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior, 155*, 237–250.

Fitzgerald, P. B., Laird, A. R., Maller, J., & Daskalakis, Z. J. (2008). A meta-analytic study of changes in brain activation in depression. *Human Brain Mapping, 29*(6), 683–695. https://doi.org/10.1002/hbm.20426

Flint, J., & Kendler, K. S. (2014). The genetics of major depression. *Neuron, 81*(3), 484–503.

Frodl, T., Jäger, M., Smajstrlova, I., Born, C., Bottlender, R., Palladino, T., Reiser, M., Möller, H.-J., & Meisenzahl, E. M. (2008). Effect of hippocampal and amygdala volumes on clinical outcomes in major depression: A 3-year prospective magnetic resonance imaging study. *Journal of Psychiatry and Neuroscience: JPN, 33*(5), 423.

Gong, Q., & He, Y. (2015). Depression, neuroimaging and connectomics: A selective overview. *Biological Psychiatry, 77*(3), 223–235. https://doi.org/10.1016/j.biopsych.2014.08.009

Gotlib, I. H., & Joormann, J. (2010). Cognition and depression: Current status and future directions. *Annual Review of Clinical Psychology, 6*, 285–312.

Gotlib, I. H., Krasnoperova, E., Yue, D. N., & Joormann, J. (2004). Attentional biases for negative interpersonal stimuli in clinical depression. *Journal of Abnormal Psychology, 113*(1), 127.

Grahek, I., Shenhav, A., Musslick, S., Krebs, R. M., & Koster, E. H. (2019). Motivation and cognitive control in depression. *Neuroscience & Biobehavioral Reviews, 102*, 371–381.

Hall, L. M. J., Klimes-Dougan, B., H. Hunt, R.,M., Thomas, K., Houri, A., Noack, E., A. Mueller, B., O. Lim, K., & R. Cullen, K. (2014). An fMRI study of emotional face processing in adolescent major depression. *Journal of Affective Disorders, 168*, 44–50. https://doi.org/10.1016/j.jad.2014.06.037

Harmon-Jones, E., & Mills, J. (2019). An introduction to cognitive dissonance theory and an overview of current perspectives on the theory. In *Cognitive dissonance: Reexamining a pivotal theory in psychology* (2nd ed., pp. 3–24). American Psychological Association. https://doi.org/10.1037/0000135-001.

Helm, K., Viol, K., Weiger, T. M., Tass, P. A., Grefkes, C., Del Monte, D., & Schiepek, G. (2018). Neuronal connectivity in major depressive disorder: A systematic review. *Neuropsychiatric Disease and Treatment, 14*, 2715–2737. https://doi.org/10.2147/NDT.S170989

Hu, W., Huang, G., Li, L., Zhang, L., Zhang, Z., & Liang, Z. (2020). Video-triggered EEG-emotion public databases and current methods: A survey. *Brain Science Advances, 6*(3), 255–287. https://doi.org/10.26599/BSA.2020.9050026

Im, H. Y., Cushing, C. A., Ward, N., & Kveraga, K. (2021). Differential neurodynamics and connectivity in the dorsal and ventral visual pathways during perception of emotional crowds and individuals: A MEG study. *Cognitive, Affective and Behavioral Neuroscience, 21*(4), 776–792. https://doi.org/10.3758/s13415-021-00880-2

Isen, A. M. (2001). An influence of positive affect on decision making in complex situations: Theoretical issues with practical implications. *Journal of Consumer Psychology, 11*(2), 75–85. https://doi.org/10.1207/S15327663JCP1102_01

Joormann, J., & Siemer, M. (2011). Affective processing and emotion regulation in dysphoria and depression: Cognitive biases and deficits in cognitive control. *Social and Personality Psychology Compass, 5*(1), 13–28.

König, A., Linz, N., Zeghari, R., Klinge, X., Tröger, J., Alexandersson, J., & Robert, P. (2019). Detecting apathy in older adults with cognitive disorders using automatic speech analysis. *Journal of Alzheimer's Disease, 69*(4), 1183–1193. https://doi.org/10.3233/JAD-181033

König, A., Mallick, E., Tröger, J., Linz, N., Zeghari, R., Manera, V., & Robert, P. (2021). Measuring neuropsychiatric symptoms in patients with early cognitive decline using speech analysis. *European Psychiatry, 64*(1), e64. https://doi.org/10.1192/j.eurpsy.2021.2236

Kaiser, R. H., Andrews-Hanna, J. R., Wager, T. D., & Pizzagalli, D. A. (2015). Large-scale network dysfunction in major depressive disorder: A meta-analysis of resting-state functional connectivity. *JAMA Psychiatry, 72*(6), 603–611.

Lemke, H., Probst, S., Warneke, A., Waltemate, L., Winter, A., Thiel, K., Meinert, S., Enneking, V., Breuer, F., & Klug, M. (2022). The course of disease in major depressive disorder is associated with altered activity of the limbic system during negative emotion processing. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 7*(3), 323–332.

Leppänen, J. M. (2006). Emotional information processing in mood disorders: A review of behavioral and neuroimaging findings. *Current Opinion in Psychiatry, 19*(1), 34. https://doi.org/10.1097/01.yco.0000191500.46411.00

Li, X., & Wang, J. (2021). Abnormal neural activities in adults and youths with major depressive disorder during emotional processing: A meta-analysis. *Brain Imaging and Behavior, 15*(2), 1134–1154. https://doi.org/10.1007/s11682-020-00299-2

Loch, N., Hiller, W., & Witthöft, M. (2011). Der cognitive emotion regulation questionnaire (CERQ). *Zeitschrift Für Klinische Psychologie Und Psychotherapie, 40*(2), 94–106.

Loeffler, L. A., Radke, S., Habel, U., Ciric, R., Satterthwaite, T. D., Schneider, F., & Derntl, B. (2018). The regulation of positive and negative emotions through instructed causal attributions in lifetime depression–A functional magnetic resonance imaging study. *Neuroimage: Clinical, 20*, 1233–1245.

Loeffler, L. A. K., Satterthwaite, T. D., Habel, U., Schneider, F., Radke, S., & Derntl, B. (2019). Attention control and its emotion-specific association with cognitive emotion regulation in depression. *Brain Imaging and Behavior, 13*, 1766–1779.

Müller, V. I., Habel, U., Derntl, B., Schneider, F., Zilles, K., Turetsky, B. I., & Eickhoff, S. B. (2011). Incongruence effects in

crossmodal emotional integration. *NeuroImage, 54*(3), 2257–2266. https://doi.org/10.1016/j.neuroimage.2010.10.047
Markus, C. R. (2013). Interaction between the 5-HTTLPR genotype, impact of stressful life events, and trait neuroticism on depressive symptoms in healthy volunteers. *Psychiatric Genetics, 23*(3), 108–116.
Menne, F., Dörr, F., Schräder, J., Tröger, J., Habel, U., König, A., & Wagels, L. (2024). The voice of depression: Speech features as biomarkers for major depressive disorder. *BMC Psychiatry, 24*(1), 794. https://doi.org/10.1186/s12888-024-06253-6
Mitterschiffthaler, M. T., Williams, S. C. R., Walsh, N. D., Cleare, A. J., Donaldson, C., Scott, J., & Fu, C. (2007). Neural basis of the emotional Stroop interference effect in major depression. *Psychological Medicine, 38*(2), 247–256.
Mundt, J. C., Snyder, P. J., Cannizzaro, M. S., Chappie, K., & Geralts, D. S. (2007). Voice acoustic measures of depression severity and treatment response collected via interactive voice response (IVR) technology. *Journal of Neurolinguistics, 20*(1), 50–64. https://doi.org/10.1016/j.jneuroling.2006.04.001
Mundt, J. C., Vogel, A. P., Feltner, D. E., & Lenderking, W. R. (2012). Vocal acoustic biomarkers of depression severity and treatment response. *Biological Psychiatry, Novel Pharmacotherapies for Depression, 72*(7), 580–587. https://doi.org/10.1016/j.biopsych.2012.03.015
Nee, D. E., Wager, T. D., & Jonides, J. (2007). Interference resolution: Insights from a meta-analysis of neuroimaging tasks. *Cognitive, Affective and Behavioral Neuroscience, 7*(1), 1–17. https://doi.org/10.3758/CABN.7.1.1
O'Shea, D. M., Dotson, V. M., Woods, A. J., Porges, E. C., Williamson, J. B., O'Shea, A., & Cohen, R. (2018). Depressive symptom dimensions and their association with hippocampal and entorhinal cortex volumes in community dwelling older adults. *Frontiers in Aging Neuroscience, 10*, 40.
Pessoa, L., McKenna, M., Gutierrez, E., & Ungerleider, L. G. (2002). Neural processing of emotional faces requires attention. *Proceedings of the National Academy of Sciences of the United States of America, 99*(17), 11458–11463. https://doi.org/10.1073/pnas.172403899
Pizzagalli, D. A. (2014). Depression, stress, and anhedonia: Toward a synthesis and integrated model. *Annual Review of Clinical Psychology, 10*, 393–423. https://doi.org/10.1146/annurev-clinpsy-050212-185606
Rauch, A. V., Reker, M., Ohrmann, P., Pedersen, A., Bauer, J., Dannlowski, U., Harding, L., Koelkebeck, K., Konrad, C., & Kugel, H. (2010). Increased amygdala activation during automatic processing of facial emotion in schizophrenia. *Psychiatry Research: Neuroimaging, 182*(3), 200–206.
Reitan, R. M. (1971). Trail making test results for normal and brain-damaged children. *Perceptual and Motor Skills, 33*(2), 575–581. https://doi.org/10.2466/pms.1971.33.2.575
Rock, P. L., Roiser, J. P., Riedel, W. J., & Blackwell, A. D. (2014). Cognitive impairment in depression: A systematic review and meta-analysis. *Psychological Medicine, 44*(10), 2029–2040. https://doi.org/10.1017/S0033291713002535
Rogers, M. A., Kasai, K., Koji, M., Fukuda, R., Iwanami, A., Nakagome, K., Fukuda, M., & Kato, N. (2004). Executive and prefrontal dysfunction in unipolar depression: A review of neuropsychological and imaging evidence. *Neuroscience Research, 50*(1), 1–11.
Saveanu, R. V., & Nemeroff, C. B. (2012). Etiology of depression: Genetic and environmental factors. *Psychiatric Clinics, 35*(1), 51–71. https://doi.org/10.1016/j.psc.2011.12.001
Scherer, S., Lucas, G. M., Gratch, J., Skip Rizzo, A., & Morency, L.-P. (2016). Self-reported symptoms of depression and PTSD are associated with reduced vowel space in screening interviews. *IEEE Transactions on Affective Computing, 7*(1), 59–73. https://doi.org/10.1109/TAFFC.2015.2440264
Schlösser, R. G., Wagner, G., Koch, K., Dahnke, R., Reichenbach, J. R., & Sauer, H. (2008). Fronto-cingulate effective connectivity in major depression: A study with fMRI and dynamic causal modeling. *Neuroimage, 43*(3), 645–655.
Schmahmann, J. D. (2019). The cerebellum and cognition. *Neuroscience Letters, 688*, 62–75. https://doi.org/10.1016/j.neulet.2018.07.005
Schräder, J., Habel, U., Jo, H.-G., Walter, F., & Wagels, L. (2023). Identifying the duration of emotional stimulus presentation for conscious versus subconscious perception via hierarchical drift diffusion models. *Consciousness and Cognition, 110*, Article 103493. https://doi.org/10.1016/j.concog.2023.103493
Schräder, J., Herzberg, L., Jo, H.-G., Hernandez-Pena, L., Koch, J., Habel, U., & Wagels, L. (2024). Neurophysiological pathways of unconscious emotion processing in depression: Insights from a simultaneous EEG-fMRI measurement. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*. https://doi.org/10.1016/j.bpsc.2024.07.005. S2451902224001939.
Seabold, S., & Perktold, J. (2010). Statsmodels: Econometric and statistical modeling with python. In *9th Python in science conference*.
Searle, S. R., Speed, F. M., & Milliken, G. A. (1980). Population marginal means in the linear model: An alternative to least squares means. *The American Statistician, 34*(4), 216–221. https://doi.org/10.1080/00031305.1980.10483031
Snyder, H. R. (2013). Major depressive disorder is associated with broad impairments on neuropsychological measures of executive function: A meta-analysis and review. *Psychological Bulletin, 139*(1), 81–132. https://doi.org/10.1037/a0028727
Spielberger, C. D., Gorsuch, L., Laux, L., Glanzmann, P., & Schaffner, P. (2001). *Das State-Trait-Angstinventar: STAI.* Beltz Test.
Stuhrmann, A., Dohm, K., Kugel, H., Zwanzger, P., Redlich, R., Grotegerd, D., Rauch, A. V., Arolt, V., Heindel, W., & Suslow, T. (2013). Mood-congruent amygdala responses to subliminally presented facial expressions in major depression: Associations with anhedonia. *Journal of Psychiatry and Neuroscience: JPN, 38*(4), 249.
Svard, J., Wiens, S., & Fischer, H. (2012). Superior recognition performance for happy masked and unmasked faces in both younger and older adults. *Frontiers in Psychology, 3*. https://doi.org/10.3389/fpsyg.2012.00520
Thapar, A., Eyre, O., Patel, V., & Brent, D. (2022). Depression in young people. *Lancet, 400*(10352), 617–631. https://doi.org/10.1016/S0140-6736(22)01012-1
Trichard, C., Martinot, J. L., Alagille, M., Masure, M. C., Hardy, P., Ginestet, D., & Féline, A. (1995). Time course of prefrontal lobe dysfunction in severely depressed in-patients: A longitudinal neuropsychological study. *Psychological Medicine, 25*(1), 79–85. https://doi.org/10.1017/S0033291700028105
Victor, T. A., Furey, M. L., Fromm, S. J., Öhman, A., & Drevets, W. C. (2010). Relationship between amygdala responses to masked faces and mood state and treatment in major depressive disorder. *Archives of General Psychiatry, 67*(11), 1128–1138.
Vorst, H. C., & Bermond, B. (2001). Validity and reliability of the Bermond–Vorst alexithymia questionnaire. *Personality and Individual Differences, 30*(3), 413–434.
Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia, 45*(1), 174–194.
Wagner, G., Sinsel, E., Sobanski, T., Köhler, S., Marinou, V., Mentzel, H.-J., Sauer, H., & Schlösser, R. G. M. (2006). Cortical inefficiency in patients with unipolar depression: An event-related fMRI study with the stroop task. *Biological Psychiatry, 59*(10), 958–965. https://doi.org/10.1016/j.biopsych.2005.10.025

Wang, J. Z., Zhao, S., Wu, C., Adams, R. B., Newman, M. G., Shafir, T., & Tsachor, R. (2023). Unlocking the emotional world of visual media: An overview of the science, research, and impact of understanding emotion. *Proceedings of the IEEE, 111*(10), 1236–1286. https://doi.org/10.1109/JPROC.2023.3273517

Wechsler, D., & Härting, C. (2000). *Wechsler-Gedächtnistest-revidierte Fassung: WMS-R; Manual; deutsche Adaptation der revidierten Fassung der Wechsler Memory scale von David Wechsler*. Huber.

Williams, J. B. (1988). A structured interview guide for the Hamilton depression rating scale. *Archives of General Psychiatry, 45*(8), 742–747.

Yang, Z., Zhao, J., Jiang, Y., Li, C., Wang, J., Weng, X., & Northoff, G. (2011). Altered negative unconscious processing in major depressive disorder: An exploratory neuropsychological study. *PLos One, 6*(7), Article e21881.

Zhang, D., He, Z., Chen, Y., & Wei, Z. (2016). Deficits of unconscious emotional processing in patients with major depression: An ERP study. *Journal of Affective Disorders, 199*, 13–20.

Zhang, J., Li, X., Du, J., Tan, X., Zhang, J., Zhang, Y., You, M., Zhao, M., Gao, Y., & Wang, J. (2021). Impairments of implicit emotional neurocognitive processing in college students with subthreshold depression: An ERP study. *Journal of Clinical Neurophysiology, 38*(3), 192–197.

Zhang, M., Wang, S., Zhang, J., Jiao, C., Chen, Y., Chen, N., Zhao, Y., Wang, Y., & Zhang, S. (2020). The effects of subliminal goal priming on emotional response inhibition in cases of major depression. *Frontiers in Psychology, 11*, 3470.

Zhong, M., Wang, X., Xiao, J., Yi, J., Zhu, X., Liao, J., Wang, W., & Yao, S. (2011). Amygdala hyperactivation and prefrontal hypoactivation in subjects with cognitive vulnerability to depression. *Biological Psychology, 88*(2–3), 233–242. https://doi.org/10.1016/j.biopsycho.2011.08.007

Zhu, J., Li, J., Li, X., Rao, J., Hao, Y., Ding, Z., & Wang, G. (2018). Neural basis of the emotional conflict processing in major depression: ERPs and source localization analysis on the N450 and P300 components. *Frontiers in Human Neuroscience, 12*. https://doi.org/10.3389/fnhum.2018.00214