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The effect of sad mood on early sensory event-related potentials to task-irrelevant faces

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ABSTRACT

It has been shown that the perceiver's mood affects the perception of emotional faces, but it is not known how mood affects preattentive brain responses to emotional facial expressions. To examine the question, we experimentally induced sad and neutral mood in healthy adults before presenting them with task-irrelevant pictures of faces while an electroencephalography was recorded. Sad, happy, and neutral faces were presented to the participants in an ignore oddball condition. Differential responses (emotional – neutral) for the P1, N170, and P2 amplitudes were extracted and compared between neutral and sad mood conditions. Emotional facial expressions modulated all the components, and an interaction effect of expression by mood was found for P1: an emotional modulation to happy faces, which was found in neutral mood condition, disappeared in sad mood condition. For N170 and P2, we found larger response amplitudes for both emotional faces, regardless of the mood. The results add to the previous behavioral findings showing that mood already affects low-level cortical feature encoding of task-irrelevant faces.

1. Introduction

Mood is an emotional state that is tightly linked to individuals' cognitive processes (Clore & Huntsinger, 2007; Dolan, 2002). For instance, people's current mood influences the processing of facial information, such as judgement (Bouhuys et al., 1995) and the recognition of facial emotions (Schmid & Schmid Mast, 2010). However, little is known about how mood influences task-irrelevant face processing and its brain basis. In the present study, we investigate how laboratory-induced sad mood compared with neutral mood affects cortical event-related potentials (ERPs) to task-irrelevant facial expressions in healthy individuals.

With high temporal resolution, ERPs enable the investigation of the brain's sensory-cognitive functions. Previous studies have found that facial expressions modulate obligatory ERPs, such as P1, N170, and P2, even when the faces are task irrelevant (MacNamara et al., 2012; Müller-Bardorff et al., 2016, 2018; Santos et al., 2008; Valdés-Conroy et al., 2014). Studies that have utilized a fast periodic presentation of stimuli or rare changes in facial expressions (i.e., an oddball condition) have found that even subtle changes in the emotional expression of faces are detected fast and automatically (Dzhelyova et al., 2017; Leleu et al., 2018). In addition, in the oddball condition, ERPs to rarely presented emotional faces among repeated neutral faces with a longer interstimulus interval and longer stimulus presentation duration (typically 400–600 ms stimulus-onset asynchrony and 200 ms stimulus duration) have shown emotional modulation even when the faces are not attended (Astikainen et al., 2013; Astikainen & Hietanen, 2009; Chang et al., 2010; Kimura et al., 2012; Kreegipuu et al., 2013; Liu et al., 2016; Stefanics et al., 2012; Zhao & Li, 2006). In these studies, responses to infrequently presented fearful and happy faces have mostly been investigated.

Of the obligatory visual ERPs, P1 is a positive polarity component that is elicited by a visual stimulus and peaking at approximately 100 ms after stimulus onset at the left and right occipital electrode sites (for faces, see, e.g., Batty & Taylor, 2003; Holmes et al., 2008; Müller-Bardorff et al., 2018; Rellecke et al., 2012). P1 is suggested to reflect an early automatic processing of faces, and its amplitude is modulated by low-level visual features in faces (Latinus & Taylor, 2006; Rossion & Caharel, 2011; Schindler et al., 2021; Vuilleumier & Pourtois, 2007). Some previous studies have reported emotional modulation of the P1

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amplitude, which is mostly found as a larger response amplitude for negative (e.g., angry, fearful) faces compared with neutral or happy faces (e.g., Pourtois et al., 2005; Rellecke et al., 2012; Smith et al., 2013; Stefanics et al., 2012; for a review, see Vuilleumier & Pourtois, 2007). However, several studies have not found emotional modulation of the P1 amplitude (Astikainen & Hietanen, 2009; Faja et al., 2016; Frühholz et al., 2011; Itier & Neath-Tavares, 2017; Jiang et al., 2009; Müller--Bardorff et al., 2016; Ruohonen et al., 2020), and one study has observed larger P1 amplitudes for neutral faces compared with happy faces (Hagemann, Straube, & Schulz, 2016).

P1 is followed by N170, which is a negative polarity component peaking at approximately 170 ms after stimulus onset at the left and right parieto-occipital sites (Astikainen et al., 2013; Batty & Taylor, 2003; Bentin et al., 1996; Ruohonen et al., 2020). For face processing, N170 is suggested to reflect early visual processing of face structure (Bentin et al., 1996; Eimer, 2000), and it is commonly modulated by facial expressions. That is, emotional faces usually elicit larger N170 amplitudes than neutral faces (e.g., Astikainen et al., 2013; Astikainen & Hietanen, 2009; Batty & Taylor, 2003; Bentin et al., 1996; Blau et al., 2007; Krombholz et al., 2007; Leppänen et al., 2007; for reviews, see Hinojosa et al., 2015; Schindler et al., 2021; however, for lack of emotional modulation of N170 see Eimer & Holmes, 2002, Eimer et al., 2003, Holmes et al., 2003).

P2 is a component that is associated with automatic attention and spatial feature processing of visual stimuli and is usually elicited by faces approximately 200 ms after stimulus onset at posterior electrode sites (Carretié et al., 2001; Latinus & Taylor, 2006; Schweinberger & Neumann, 2016). Some studies have reported larger P2 amplitudes to non-negative than negative faces (e.g., happy and neutral vs. fearful faces, Itier & Neath-Tavares, 2017; neutral vs. angry faces, Raz et al., 2014; happy vs. fearful faces, Stefanics et al., 2012; however, for larger P2 to neutral than happy faces see Raz et al., 2014), while some have reported larger P2 responses to negative faces compared with non-negative faces (e.g., angry and fearful vs. happy and neutral, Calvo et al., 2013), or no effects of facial expression on P2 responses (Peschard et al., 2013; Zhao & Li, 2006). In sum, the results of the emotional modulation of P2 to face stimuli have shown mixed results. The studies have included threatening faces (fearful and angry), but there is a lack of research using sad faces in stimulus materials.

In addition to modulation due to emotional expressions, the obligatory ERPs to faces are modulated by the context in which they are presented (for a review, see Wieser & Brosch, 2012). For instance, P1 was larger in amplitude when emotional facial expression and body expression were congruent than incongruent (Meeren et al., 2005). A study using an affective priming paradigm showed that the N170 response to a face was larger in amplitude when an affectively congruent versus incongruent picture was presented before it (happy faces elicited a larger response when presented after positive vs. negative primes, while sad faces elicited a larger response when presented after negative vs. positive primes; Astikainen & Hietanen, 2013). Increased N170 responses were also found when the faces were presented in fearful scenes compared with neutral scenes (Righart & de Gelder, 2006), and a larger N170 amplitude to fearful faces was observed when the faces and scenes were congruent (Righart & de Gelder, 2008). To the best of our knowledge, there are no studies investigating the effect of contextual information on the P2 response to facial expressions.

The obligatory ERPs to facial expressions are also affected by viewer-related factors. For example, a larger P1 amplitude was also observed for disgusted faces compared with neutral faces after experiencing social exclusion (Kawamoto, Nittono, & Ura, 2014). In addition, altered brain responses have been observed in several different neurodevelopmental and psychiatric conditions (Kremláček et al., 2016). Perceptual processing of sad faces has been investigated especially in mood disorders. For example, previous studies have found that in depressive disorder early cortical ERPs are altered specifically to sad faces in relation to neutral faces (for so called negative information processing bias in depression, see Beck, 2008; for related empirical evidence, see Chang et al., 2010; Dai & Feng, 2012; Ruohonen et al., 2020; Wu et al., 2016; Zhang et al., 2016; Zhao et al., 2015). However, it is not known whether these brain responses show a similar negative bias in healthy participants when they are in sad mood.

In the present study, we investigate the effect of sad mood on perceptual ERPs (i.e., P1, N170, and P2) to faces by experimentally inducing sad and neutral mood in healthy adults (a within-subjects design). We follow a previous study's mood induction procedure (Robinson et al., 2012), utilizing Velten's mood statements and music to induce the target moods. After the mood induction procedure, we present the participants with sad and happy deviant faces interspersed with neutral standard faces in an ignore oddball paradigm (as in Ruohonen et al., 2020). We investigate the emotional modulation of ERPs by calculating differential ERPs to the emotional facial expressions (emotional - neutral) at the different processing stages of face perception as reflected by P1, N170, and P2 (Astikainen & Hietanen, 2009; Chang et al., 2010; Stefanics et al., 2012; Zhao & Li, 2006).

If a similar negative bias exists in sad mood as in clinical depression, it can be expected that ERPs would show altered amplitudes of differential responses to sad faces in sad mood compared with neutral mood. This hypothesis is based on previous studies showing larger ERP responses to sad faces in depressed participants (Dai & Feng, 2012; Ruohonen et al., 2020; Wu et al., 2016; Zhang et al., 2016; Zhao et al., 2015), although one study using an ignore oddball condition has reported smaller ERP amplitudes in depressed than non-depressed participants (Chang et al., 2010). Previous behavioral studies applying mood induction methods have also found mood-congruent effects on conscious face recognition tasks (Bouhuys et al., 1995; Schmid & Schmid Mast, 2010). However, it is unclear whether a similar effect as that found for conscious recognition tasks can be expected for task-irrelevant processing of faces reflecting automatic sensory functions of the brain.

2. Materials and methods

2.1. Participants

The research protocol was carried out in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the University of Jyväskylä. Written informed consent was obtained from all the participants before the measurement started. The sample size was estimated with a priori power analysis implemented with G*Power (version 3.1; Faul, Erdfelder, & Lang, 2007) based on medium effect size ($\eta_p^2 = 0.06$; Cohen, 1988). There were no mood induction studies investigating the mood effect on task-irrelevant face processing, and previous studies investigating ERP modulations (P1, N170, and P2) to the facial expressions on the manipulation of congruent affective contexts have rarely reported the effect size. Therefore, we estimate a medium effect size for the present study based on previous oddball studies showing emotional modulation of early ERPs to faces in healthy participants (Kimura et al., 2012; Stefanics et al., 2012) and in methodological similar studies comparing depression patients and healthy controls (e.g., Ruohonen et al., 2020; Zhang et al., 2016). A repeated measures ANOVA was set for the a priori power analysis, with Mood (Neutral vs. Sad), Expression (Sad-Neu vs. Happy-Neu), and Hemisphere (Left vs. Right) as within-subjects factors. The effect size specifications are set as in G*Power 3.0. The result of the calculation showed a requirement of 19 participants to achieve a statistical power of (1 - β) = 0.90 and a significance level of $\alpha = 0.05$.

Thirty-two healthy participants who were native Finnish speakers volunteered for the study. The participants were recruited via the email lists of the University of Jyväskylä and through the advertisement flyers in Jyväskylä. The inclusion criteria for all participants were age between 18 and 40 years, right-handedness, normal or corrected-to-normal vision, and no self-reported history of psychiatric disorders, brain trauma or neurological diseases. Participants who had a score of 10 or higher in Beck's Depression Inventory-II (BDI-II; Beck et al., 1996) were excluded, because the depressive symptoms have effects on ERPs to emotional faces (Ruohonen et al., 2020). Females who were pregnant or breastfeeding were also excluded from the experiments because of the hormonal changes. The efficiency of mood induction was also considered as a criterion for inclusion. Participants who evaluated their mood to sad direction with 10% changes from the baseline on the sad mood measurement day were included.

Ten participants were excluded from the final sample: one due to the exclusion criteria based on BDI scores, five due to the insufficient number of trials in their EEG data caused by excessive EEG artifacts, and four had inefficient mood induction. Therefore, in total, there were twenty-two participants included in the final sample. The demographics of the participants included to the data are reported in Table 1.

2.2. Procedure

Neutral mood and sad mood were induced for all participants on two separate days in a counterbalanced order between the participants. That is, half of the participants had neutral mood induction on the first measurement day and sad mood induction on the second day, and for another half of the participants this order was reversed. For each measurement day, the procedures were the same and consisted of three main parts: a Mood Induction procedure, an experiment of Masked face detection, and an experiment of Task-irrelevant face perception (an ignore oddball paradigm). Before and after the Mood Induction procedure, the Masked face detection experiment, and the Task-irrelevant face perception experiment, participants were asked to self-evaluate their mood by drawing a vertical line in the Visual Analog Mood Scale (VAMS; Luria, 1975). The scale ranges from very sad (0 cm) to very happy (10 cm). In the present study, results of the mood evaluation (VAMS) and the Task-irrelevant face perception experiment are reported. The procedure and the stimulus paradigm of the study is illustrated in Fig. 1.

When the participants arrived at the lab on the first measurement day, they were asked to fill the BDI-II before the recording. During the experiments, participants were seated on a chair in a sound and electricity proof shielding room and monitored via a video camera. The stimuli (mood statements and facial images) were presented at the center of a 58.4 cm (23 in.) computer screen (Asus VG236H, 1920 × 1080 pixels, refresh rate 100 Hz). The screen was 1 m in front of the participant, and there was a speaker on the ceiling above the participant to play the music during mood induction procedure. The volume of the music was adjusted for each participant at an appropriate level. The lights were turned off during the whole measurement. To help the participants stay in the neutral/sad mood without disturbance from the researcher, all the instructions were given before the measurement began. The instructions for the tasks were also presented on the screen before each section, which helped the participants easily start and continue the experiment by themselves.

For each measurement day, the recording started with a two-minute resting stage that included a one-minute eyes open and a one-minute eyes closed sessions. After the resting stage recording, the participants started the mood induction procedure by pressing a button. During the mood induction procedure, every statement was presented for 15 s. Music was played at the same time until participants read all the statements. The duration of the mood induction procedure was approximately 15 min. After that, the Masked face detection experiment started in which participants evaluated whether the presented face was a sad face or a neutral face (data from this experiment are not reported here). After the Masked face detection experiment, there was a 2-minute break while the music of the target mood was playing again, which was intended to help participants get back to the mood before the Task-irrelevant face perception experiment.

Table 1
Demographic information of the participants. SD = standard deviation, BDI-II = Beck's Depression Inventory, Second Edition.

Variable		Participants (n = 22)
Age	Mean (SD)	26.6 years (4.4 years)
	Range	20–38 years
Gender	Male	10
	Female	12
BDI-II	Mean (SD)	2.05 (2.17)
	Range	0–7

Here we report the results from the Task-irrelevant face perception experiment. It utilized an ignore oddball stimulus condition, in which participants were instructed to keep their gaze at the center of the screen while concentrate on a calculation task by continuously adding 6 in the calculation in their mind and ignore the facial stimuli. The participants were asked to tell their results of the calculation twice between the stimulus presentation.

For all the measurements, E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA, USA) was used to control the presentation of the stimuli.

2.3. Materials for mood induction procedure

In accordance with a previous study (Robinson et al., 2012), Velten's mood statements (Velten, 1967) and music, obtained from neutral and sad conditions, were utilized to induce the target mood (either neutral or sad).

There were 60 one-sentence statements applied for the neutral and sad mood induction. For the neutral mood induction, statements described the general knowledge or objective facts (e.g., 'The Chinese language has many dialects, including Cantonese, Mandarin, and Wu.'). For the sad mood induction, statements were specific to self-devaluation and somatic symptoms related to depression (e.g., 'I have too many bad things in my life.'). The mood statements were translated from English to Finnish. A few statements were modified to fit into the present Finnish expression style and culture. The original and translated statements are presented in Supplementary Table 1. During the neutral mood induction, each sentence was presented to the screen in black color on a white background. During the sad mood induction, the sentence was presented in grey color and the background was blue. Concerning the music for mood induction, Adagio in G Minor by Tomaso Albinoni was selected for the sad mood, and The Planets, Op. 32: VII Neptune, the Mystic by Gustav Holst was used to induce the neutral mood. The design of sentence presentation and the music selections were made based on a previous study (Robinson et al., 2012).

2.4. Face stimulus presentation in the ERP recording

Sad, happy and neutral faces were selected from the KDEF stimulus set (The Karolinska Directed Emotional Faces; Lundqvist et al., 1998). The selections were made based on the evaluations of unbiased hit rates (a probability combined with correctness of identifying stimulus and correctness of using response) of each facial expression in a previous study (Goeleven et al., 2008). The average unbiased hit rates of all the expressions were more than 0.79 (all unbiased hit rates for sad > 0.58; for happy > 0.8; and for neutral > 0.73). Actors for face materials were 6 females and 6 males (age between 20 and 30 years). All the selected facial images were converted into grey scale in order to adjust their luminance to an equaled mean level by using a MATLAB toolbox (SHINE: spectrum, histogram, and intensity normalization and equalization; Willenbockel et al., 2010). After that, the facial images were covered by a grey frame in order to only present the inner region of the faces. The faces were presented at a visual angle of $3.03^\circ \times 4.11^\circ$, and the resolution of the facial images was 209 × 283 pixels (width × height). The list of the KDEF Ids and mean luminance of all the stimuli used in the experiment is showed in Supplementary Table 2.

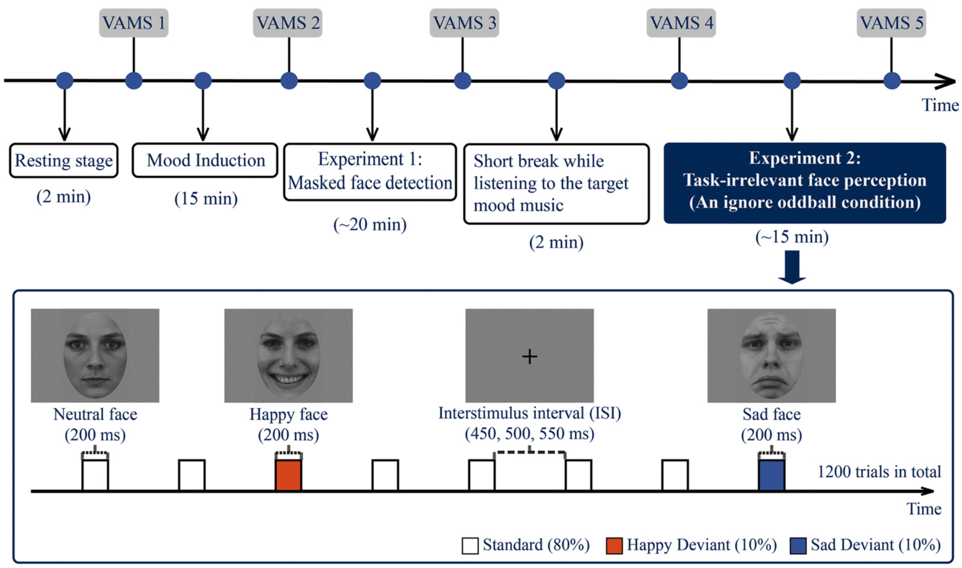

Fig. 1. Illustration of the procedure and the stimulus paradigm applied for both measurement days. For the neutral mood condition, neutral statements and music were presented in the Mood Induction procedure; for the sad mood condition, sad statements and music were presented in the Mood Induction procedure. The other parts of the measurement were kept the same for both measurement days. In the present report, results of the mood evaluation (VAMS) and the Task-irrelevant face perception experiment are reported. The faces in the figure are examples from the actual experiment (The Karolinska Directed Emotional Faces; Lundqvist et al., 1998; stimulus set: AF01NES, AF07HAS, AM05SAS). VAMS = Visual Analog Mood Scale.

In the oddball condition, a neutral 'standard' face (p = 0.8) was interspersed with a sad or a happy 'deviant' face (p = 0.1 for each deviant type). The stimuli were presented in a pseudo-random order with a restriction that there were at least two standard faces between consecutive deviant faces, and the facial identity in the pictures changed from trial to trial. The stimulus duration was 200 ms, and the interstimulus interval (ISI) was randomly either 450 ms, 500 ms, or 550 ms. The ignore oddball condition took about 15 min and 1200 facial stimuli (960 neutral standard faces, 120 sad and 120 happy deviant faces) were presented.

2.5. EEG recording and analysis

Continuous EEG was recorded by a NeurOne system (Bittium Biosignals Ltd, Kuopio, Finland) with a 128-channel HydroCel Geodesic Sensor Net (HydroCel Geodesic Sensor Net, Electric Geodesic Inc, USA). The data were recorded at a 1000 Hz sampling rate and were filtered online with a 250 Hz high cut-off. The vertex electrode (Cz) was set as the reference electrode during the recording.

The EEG data were pre-processed with MNE python (Gramfort, 2013; MNE version: 0.21.2; Python: 3.8.6). First, bad channels with an extensive amount of noise were interpolated using the spherical spline method (Perrin et al., 1989). Next, the electrode signals were band-pass filtered at 0.1–30 Hz (zero-phase overlap-add FIR filtering). The lower transition bandwidth was 0.1 Hz (−6 dB cutoff frequency: 0.05 Hz), and the upper transition bandwidth was 7.5 Hz (−6 dB cut-off frequency: 33.755 Hz). The filter length was 33001 samples (33.001 s). The data were re-referenced offline to an average over all channels. Then, data were segmented into epochs from 100 ms before and 600 ms after the onset of the stimulus. Baseline correction was applied for each epoch by subtracting the mean voltage of the 100 ms pre-stimulus period from all data points of the epoch. Bad epochs with eye blinks and other artifacts were semiautomatically removed when the epoch exceeded an amplitude of ± 50 μV.

For each mood condition (sad mood vs. neutral mood), epochs were averaged separately for responses to each deviant stimuli (sad deviant and happy deviant) and for responses to the standard stimuli immediately preceding the deviants (pre-sad neutral standard and pre-happy neutral standard), allowing the same maximum number of trials for each stimulus category. Data were included for further analysis if there were at least 40 epochs available for each deviant and standard stimulus in each mood condition.

For P1, N170, and P2, mean amplitude values were investigated. Based on previous literature (Astikainen et al., 2013; Batty & Taylor, 2003; Ruohonen et al., 2020) and visual inspection of the grand averaged data, time windows and electrode clusters at the left and right occipital/parieto-occipital sites were selected for P1, N170, and P2 separately (Supplementary Fig. 1). For each participant, the maximum or minimum response amplitude, depending on the polarity, for each component were first detected within each electrode cluster. For P1 and P2, the maximum amplitude values were detected within 80–150 ms and within 180–260 ms after stimulus onset, respectively. For N170, the minimum amplitude value was detected within a time window of 130–210 ms after the stimulus onset. After locating the maximum/minimum response amplitude, for each component a mean amplitude value from a 20-ms time window (± 10 ms around the maximum response amplitude) was calculated as an average of the electrode cluster. Next, differential responses of mean amplitudes (sad/happy deviant minus neutral standard) were calculated for P1, N170, and P2 to extract responses to emotional faces. The differential responses were used because they can index the emotional modulation of the component.

2.6. Statistics

For the ratings of mood evaluation, VAMS1 (mood evaluation scores after resting stage), VAMS 2 (mood evaluation scores after the Mood Induction procedure), and VAMS4 (mood evaluation scores before the Task-irrelevant face perception experiment) were analyzed separately and compared between the neutral and sad mood induction measurement days (Fig. 1). Two-tailed paired samples t-tests with the boot-strapping method using 1000 permutations (Good, 2005) were applied to explore the mood changes.

For the ERP amplitude, differential responses (deviant minus standard) for P1, N170, and P2 were extracted separately for sad and happy faces and submitted to repeated measures of analysis of variance (ANOVA) to investigate effects of mood on different perceptual phases. Within-subjects factors were Mood (Neutral vs. Sad), Expression (Sad-Neu vs. Happy-Neu), and Hemisphere (Left vs. Right). Two-tailed paired samples t-tests with the boot-strapping method using 1000 permutations (Good, 2005) were carried out to further investigate the significant interactions related to the effect of mood found in ANOVAs. The differential responses to sad and happy faces were compared separately between sad and neutral mood.

Whenever a significant mood related main or interaction effect was found for the differential responses, the differential responses were compared against zero by using one sample t-tests to explore whether the emotional modulation was observed in each mood condition. When no effect of mood or its interaction was found, the emotional modulation was investigated by calculating differential responses over Mood and Hemisphere separately for happy and sad faces and comparing them against zero (one sample t-tests).

The *p*-values ($p_{\text{FDR-corrected}}$) were corrected with the False discovery rate (FDR; Benjamini & Yekutieli, 2001) procedure whenever there were more than two paired samples t-tests or two one sample t-tests. Partial eta squared (η_p^2) and Cohen's d with pooled standard deviation (Cohen, 1988) are reported as effect size estimates for ANOVAs and t-tests, respectively. All statistics with *p*-values smaller than 0.050 were considered significant. The statistical analysis was conducted by using IBM SPSS Statistics Version 26 (Armonk, NY: IBM Corporated).

In addition, Bayes factor analyses (Bayesian t-tests) were conducted by utilizing JASP software (Version 0.16.4; JASP Team, 2022) to compare the relative evidence for two competing hypotheses: an alternative hypothesis and a null hypothesis. A Bayes factor (BF_{10}) greater than 1 indicates that the acceptance of the alternative hypothesis is more supportive, while a BF_{10} less than 1 can be labelled as no evidence in favour of the alternative hypothesis. According to Jeffreys (1998), a BF_{10} greater than 3 can be considered as moderate evidence and a BF_{10} greater than 10 indicates strong evidence in favour of the alternative hypothesis. Therefore, when a result is not statistically significant according to the *p*-value while a BF_{10} is greater than 1 but less than 3, we define it as insufficient evidence to draw a conclusion for or against either hypothesis.

3. Results

3.1. Mood induction

A paired-sample t-test showed that there was a significant difference in the scores of VAMS between the scores measured after the mood induction procedure (VAMS 2) in neutral mood condition (M = 5.20 cm, SD = 0.62) and the scores of VAMS in sad mood condition (M = 2.99 cm, SD = 1.24), $t(21) = 8.26$, $p < 0.001$, $p_{\text{FDR-corrected}} = 0.003$, 95% CI [1.65, 2.76], Cohen's d = 1.76. This reflects a successful mood induction. When comparing the VAMS scores before the Task-irrelevant face perception experiment (VAMS 4), paired-sample t-test reveal a significant difference between the neutral mood condition (M = 5.02 cm, SD = 0.65) and the sad mood condition (M = 2.69 cm, SD = 1.14), $t(21) = 9.69$, $p < 0.001$, $p_{\text{FDR-corrected}} = 0.003$, 95% CI [1.83, 2.83], Cohen's d = 2.07, reflecting that the sad mood maintained at least until the Task-irrelevant face perception experiment began. The scores of VAMS after resting stage (VAMS 1, baseline before the mood induction procedure) did not differ between the two measurement days, $p = 0.075$, $p_{\text{FDR-corrected}} = 0.138$. The results of mood evaluation are illustrated in Fig. 2.

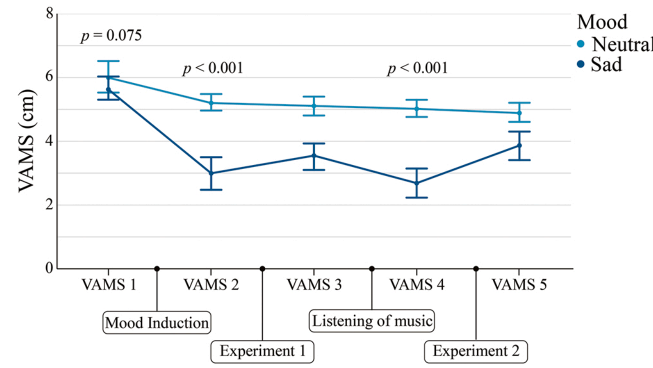

Fig. 2. Mood evaluation scales at the baseline stage (VAMS 1), after the Mood Induction procedure (VAMS 2), after the Masked face detection experiment (Experiment 1; VAMS 3), before the Task-irrelevant face perception experiment (Experiment 2; VAMS 4), and after the Task-irrelevant face perception experiment (VAMS 5). Dots show the mean values of VAMS ratings and error bars represent 95% confidence intervals. VAMS = Visual Analog Mood Scale. Uncorrected *p*-values are presented in the figure.

3.2. P1

For descriptive purposes, the waveforms, and topographic maps of the grand-averaged P1 responses to sad, happy, and neutral faces in each mood are illustrated in Fig. 3. Mean amplitude values of the P1 responses to sad, happy, and neutral faces in each mood and over mood conditions is shown in Table 2.

Differential responses for P1 (emotional-neutral) submitted to the three-way repeated measures ANOVA with within-subject variables Mood (Neutral vs. Sad), Expression (Sad-Neu vs. Happy-Neu), and Hemisphere (Left vs. Right) showed a main effect of Expression, $F(1,21) = 9.177$, $p = 0.006$, $\eta_p^2 = 0.304$. The main effect was modified by an interaction effect of Mood and Expression, $F(1,21) = 8.022$, $p = 0.010$, $\eta_p^2 = 0.276$. When comparing the response between neutral and sad mood separately for sad and happy differential responses, P1 differential responses to happy faces were more negative in amplitude in neutral mood condition (M = −0.53 μV, SD = 0.78) than in sad mood condition (M = −0.02 μV, SD = 0.88): $t(21) = -2.132$, $p = 0.045$, 95% CI [− 1.01, − 0.01], Cohen's d = 0.61, $BF_{10} = 1.459$. No differences were found between the mood conditions in sad face responses: $p = 0.410$, $BF_{10} = 0.306$. The results are illustrated in Fig. 4.

One-sample t-tests comparing the differential response against zero were conducted for the P1 differential responses for happy and sad faces to investigate whether the emotional modulation was significant. In neutral mood, the P1 differential responses for happy face, $t(21) = -3.196$, $p = 0.004$, $p_{\text{FDR-corrected}} = 0.033$, 95% CI [− 1.14, − 0.21], Cohen's d = 0.681, $BF_{10} = 10.075$, were significant against zero after the FDR procedure. For the sad face, the FDR corrected p-value did not indicate differences against zero, but Bayes factor was greater than 1 and less than 3, indicating an absence of evidence: $t(21) = 2.107$, $p = 0.047$, $p_{\text{FDR-corrected}} = 0.196$, 95% CI [0.01, 0.883], Cohen's d = 0.49, $BF_{10} = 1.401$. In sad mood, the P1 differential responses were non-significant against zero for both happy, $p = 0.907$, $p_{\text{FDR-corrected}} > 0.999$, $BF_{10} = 0.224$, and sad face, $p = 0.601$, $p_{\text{FDR-corrected}} > 0.999$, $BF_{10} = 0.253$, and for both faces the Bayes factors < 1.

There were no other main or interaction effects observed based on the three-way repeated measures ANOVA, all *p*-values > 0.113.

3.3. N170

For descriptive purposes, the waveforms, and topographic maps of the grand-averaged N170 responses to sad, happy, and neutral faces in each mood are illustrated in Fig. 5. Grand-averaged amplitude values of the N170 responses to sad, happy, and neutral faces in each mood and over mood conditions are shown in Table 2.

For the differential responses of N170, a three-way repeated measures ANOVA with within-subject variables Mood (Neutral vs. Sad), Expression (Sad-Neu vs. Happy-Neu), and Hemisphere (Left vs. Right) showed a main effect of Hemisphere, $F(1,21) = 5.240$, $p = 0.033$, $\eta_p^2 = 0.2$. The N170 differential responses (emotional-neutral) were larger at the right hemisphere (M = −0.81 μV, SD = 0.66) than at the left hemisphere (M = −0.43 μV, SD = 0.35). There were no other main or interaction effects, all *p*-values > 0.086. The results are illustrated in Fig. 5.

Emotional modulation of N170 was investigated by using one-sample t-tests comparing the differential response against zero. The N170 differential response over Mood and Hemisphere for happy and sad faces were applied. The N170 differential response for both happy, $t(21) = -5.784$, $p < 0.001$, 95% CI [− 0.77, − 0.36], Cohen's d = 1.23, $BF_{10} = 9829$, and sad faces $t(21) = -6.502$, $p < 0.001$, 95% CI [− 0.91,

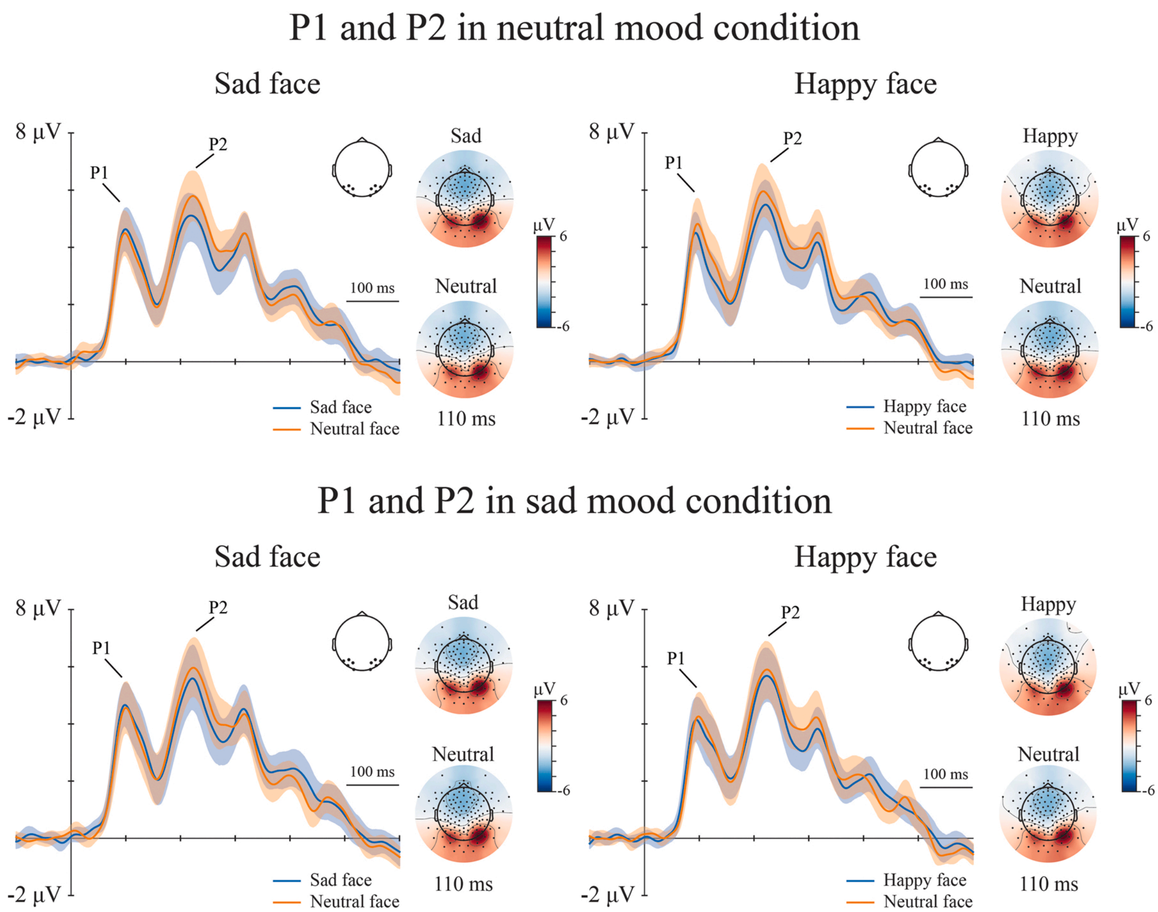

Fig. 3. Grand-averaged waveforms for P1 and P2 to sad, happy, and neutral faces and topographic maps for P1. The shadows in all the waveforms represent 95% confidence intervals.

Table 2
Mean amplitude values of the P1, N170 and P2 responses to sad, happy, and neutral facial expressions in neutral mood, sad mood, and over mood conditions. SD = standard deviation.

ERP	Expression	Amplitude (μV)		
		Neutral mood	Sad mood	Average of mood conditions
P1 Mean (SD)	Sad face	5.35 (1.55)	5.28 (1.70)	5.32 (1.55)
	Happy face	4.82 (1.51)	4.89 (1.73)	4.86 (1.55)
	Neutral face	5.20 (1.64)	5.05 (1.82)	5.13 (1.67)
N170 Mean (SD)	Sad face	-1.22 (1.47)	-1.13 (1.50)	-1.18 (1.40)
	Happy face	-1.14 (1.19)	-0.82 (1.50)	-0.98 (1.31)
	Neutral face	- 0.43 (1.26)	-0.48 (1.28)	-0.45 (1.23)
P2 Mean (SD)	Sad face	5.74 (2.09)	6.00 (2.66)	5.87 (2.26)
	Happy face	5.83 (2.13)	6.14 (2.31)	5.98 (2.13)
	Neutral face	6.31 (2.17)	6.32 (2.45)	6.32 (2.21)

− 0.47], Cohen's d = 1.39, BF_{10} = 2255, were significant against zero, reflecting robust emotional modulation of the N170 amplitude.

3.4. P2

Grand-averaged waveforms of P2 to each facial expression are illustrated in Fig. 3 for descriptive purposes. Mean amplitude values of the P2 responses to sad, happy, and neutral faces in each mood and over mood conditions are shown in Table 2.

For the differential responses of P2, a three-way repeated measures ANOVA with within-subject variables Mood (Neutral vs. Sad), Expression (Sad-Neu vs. Happy-Neu), and Hemisphere (Left vs. Right), showed no main or interaction effects, all p-values > 0.123.

Emotional modulation of P2 was investigated by using one-sample t-tests comparing the differential response against zero. The P2 differential response over Mood and Hemisphere for happy and sad faces were applied. The P2 differential response for both happy, $t(21) = -2.554$, $p = 0.018$, 95% CI [− 0.99, − 0.09], Cohen's d = 0.55, BF_{10} = 2.991, and sad faces $t(21) = -3.024$, $p = 0.006$, 95% CI [− 1.10, − 0.18], Cohen's d = 0.65, BF_{10} = 7.194, were significant against zero, indicating robust emotional modulation of the P2 amplitude.

4. Discussion

The main purpose of the present study was to investigate the effects of sad mood on ERPs to task-irrelevant processing of facial expressions. By applying a mood induction procedure, we successfully elicited sad and neutral mood on separate days in healthy participants. We found a robust emotional modulation of the P1 amplitude for happy faces in

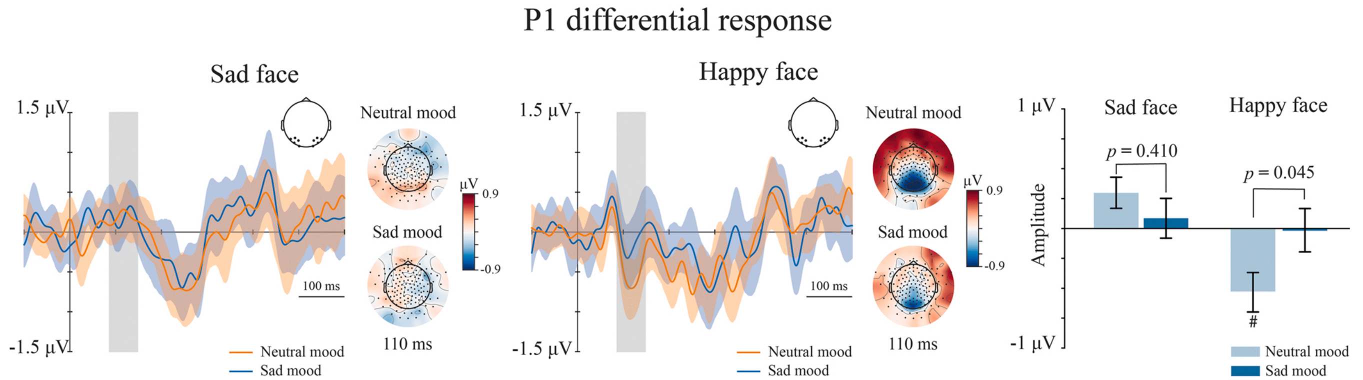

Fig. 4. Waveforms and topographic maps of the P1 differential responses in neutral and sad mood. The shadows in the waveforms represent 95% confidence intervals. The grey rectangle shadows in the waveforms of differential responses show the time window applied in the analysis to detect the maximum response amplitude. In the analysis, a mean amplitude value of ± 10 ms around the maximum response amplitude was applied. The error bars in the bar charts represent standard error of mean. Uncorrected *p*-values are presented in the figure. #significant against zero (one sample t-test).

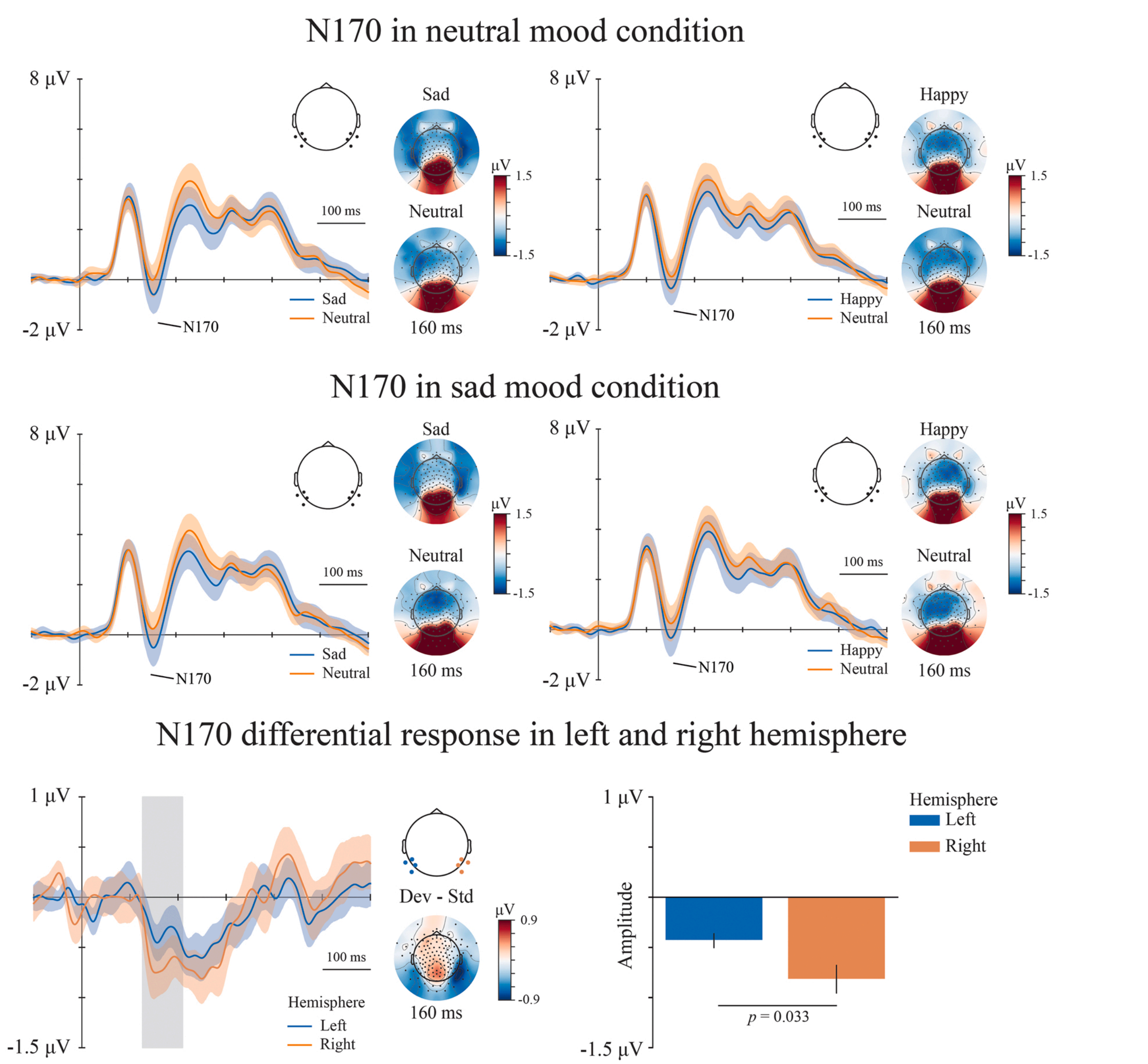

Fig. 5. Grand-averaged waveforms and topographic maps of N170 responses to sad, happy, and neutral faces and the N170 differential responses. For the differential waveforms, the responses are averaged over the sad and happy expressions and the sad and neutral moods. The shadows in all the waveforms represent 95% confidence intervals. The grey rectangle area in the waveforms of differential response shows the time window applied in the analysis to detect peaks for individual participants. In the analysis, a mean amplitude value of ± 10 ms around the peak was applied. The error bars in the bar charts represent standard error of mean.

neutral mood, which disappeared during sad mood. N170 and P2 did not show modulation by mood, but they were found to be modulated by emotion. Next, we discuss these findings in detail.

P1 showed an interaction effect of mood by emotion: In neutral mood, the differential P1 response to happy faces was significant against zero, reflecting the emotional modulation of P1. In sad mood, the differential response to happy faces was nonsignificant, suggesting no emotional modulation in sad mood, and Bayes factors smaller than 1 also supported this interpretation. The results from the post hoc tests breaking the interaction effect in ANOVA by directly comparing the responses between sad and neutral mood were in line with the analysis comparing differential responses to zero. The same comparison for sad faces supported the null hypothesis (no difference between the mood conditions). Because P1 reflects visual feature encoding, our results from neutral mood can be interpreted as automatic encoding of happy faces and possibly a less robust encoding of sad faces. The more robust differential response to happy than sad faces can possibly be associated with more recognizable low-level features of happy than sad faces (Calvo & Lundqvist, 2008; Leppänen & Hietanen, 2007; Tottenham et al., 2009). Since we used differential responses in the analyses, our results may also reflect neural discrimination of happy faces from neutral faces. Interestingly, P1 modulation by happy faces disappeared when the participants were in sad mood, potentially reflecting disrupted encoding of happy faces in sad mood. In general, this result is in line with previous studies showing context effects (for P1, see Meeren et al., 2005; Kawamoto, Nittono, & Ura, 2014; for N170, see Chen et al., 2020; Hietanen & Astikainen, 2013; Righart & de Gelder, 2008; for LPP, see Xu et al., 2017) on ERPs to facial expressions. However, the current study is the first to show the effect of mood on task-irrelevant processing of facial expressions. Thus, it seems to be that sad mood affects not only the conscious detection of facial expressions (Bouhuys et al., 1995; Chepenik et al., 2007), but also task-irrelevant encoding of facial features.

Our result regarding the mood effect on P1 amplitude is also in line with a previous study investigating the effect of affective visual context on automatic auditory change detection in healthy individuals (Pinheiro et al., 2017). In the study, the participants were presented with a contextual affective picture (neutral, negative, or positive) while ERPs to changes in sound were measured. The authors interpreted that the negative contextual pictures disrupted participants' predictive processing of unattended sounds, which was reflected by decreased mismatch negativity (MMN) amplitudes to the deviant sounds presented in the context of negative pictures. Analogously, in the present study, we found that sad mood disrupted the encoding of happy faces, as reflected by decreased P1 amplitude, to faces presented in the oddball condition.

MMN-responses in the auditory modality reflect change detection, and they have also been interpreted as an error signal arising from a conflict between a sensory prediction and sensory inputs (Garrido et al., 2009; Wacongne et al., 2012; for predictive coding theory see, Friston, 2005). A visual counterpart of the auditory MMN, called the visual MMN (vMMN), has been widely reported to different changing visual features, including facial expressions (Astikainen et al., 2013; Astikainen & Hietanen, 2009; Chang, et al., 2010; Kimura et al., 2012; Stefanics et al., 2012; Xu et al., 2018; Zhao & Li, 2006). It is notable that in many studies reporting the vMMN to emotional faces, the responses may reflect not only the predictive processing of the deviant faces, but also an emotional modulation of the responses. This is because, in many studies, the standard face in the oddball condition has been neutral regarding emotion, while the deviant face has been emotional (e.g., Astikainen & Hietanen, 2009; Chang et al., 2010; Liu et al., 2016; Zhao & Li, 2006). Because we applied an oddball condition, it is possible that our results also reflect predictive coding of emotional faces. However, we have some reasons to believe that the responses in our study are modulated by emotional expressions. Firstly, some previous studies have directly investigated this issue. In one study (Astikainen et al., 2013), differential responses to fearful and happy faces were compared when presented either with a low probability among neutral faces (an oddball condition) or with equal probability with neutral faces (an equiprobable condition). No difference was found between independent components' amplitudes between these stimulus conditions within 100–200 ms latency, suggesting that the amplitude modulations within this time interval reflect an effect of facial emotion rather than stimulus probability on ERPs. Two studies applied both neutral and emotional deviant faces in the oddball condition, finding an amplitude modulation only for emotional but not for neutral faces presented with low probability (fearful faces: Rosburg et al., 2019a, 2019b; angry faces: Kovarski et al., 2017). Kimura and the colleagues (2011) applied a design where physically identical faces were compared as standard and deviant stimulus, and they found probability-related effects only with a later latency (approximately 280 ms after the onset of the fearful faces and 350 ms after the onset of the happy faces). Similarly, Stefanics et al. (2012) observed probability-related effects mainly within the 150–220 ms and 250–360 ms latencies, but the emotional modulation of ERPs as early as 80–120 ms after the onset of faces (fearful deviants vs. happy deviants). Specifically related to P1, Kovarski and colleagues (2017) found an increased amplitude for both angry deviant face (in comparison to neutral standard in the oddball condition) and angry face presented in equal probability with other facial expressions. In sum, these previous findings do not associate P1 to vMMN, which is defined as increased response to low-probability deviant in contrast to standard stimulus, but instead, they suggest that emotional modulation explains differential responses within P1 latency. Therefore, we are prone to interpret our P1 finding in neutral mood more as an emotional modulation than a prediction error signal reflecting detection of a regularity violation in facial emotion. Moreover, because P1 to sad faces did not show similar robust differential responses against neutral faces as the happy faces in neutral mood, even if the probability for the sad and happy faces was the same, it can be expected that facial emotion rather its probability caused this amplitude modulation.

Our findings regarding P1 modulation due to mood manipulation were different from those showing ERP alterations in depression patients. In a previous study in depression patients, the differential P1 response to sad faces was greater compared with controls, reflecting negative bias in information processing in depression (Ruohonen et al., 2020). In this previous study, the P1 response also indicated a depressive state because the P1 amplitude normalized when the participant recovered from depression. In the present study, significant modulation of P1 to sad faces was observed neither in the neutral nor sad mood. Thus, it seems that early perceptual encoding of facial emotions, as reflected by the P1 amplitude, is not affected similarly by mood and depressive state. This implies that, if the finding of increased P1 amplitude to sad faces in depression (Ruohonen et al., 2020) will be repeated in future studies, P1 may have potential to be utilized as a biomarker for a depressive state.

Our study did not find evidence of a mood-congruent effect on ERPs (i.e., larger ERP responses to sad faces when the participants were in sad mood compared with the responses in neutral mood), which has been a common finding in previous behavioral studies. Previous behavioral studies applying mood induction methods have reported a mood-congruent effect in attended recognition tasks for faces and words (Bouhuys et al., 1995; Chepenik et al., 2007). In the present study, the participants were asked to focus on mathematical calculations while they passively viewed the faces. Future studies on task-irrelevant facial expression processing should investigate whether attentive processing of faces is more prone to mood-congruent effects than non-attentive processing.

In the present study, the mood effect was found neither for N170 nor P2. However, emotional modulation was evident for both N170 and P2. Previous studies have shown that facial expressions can modulate the amplitude of these responses (for a review of N170, see Hinojosa et al., 2015; for P2, see Calvo et al., 2013; Itier & Neath-Tavares, 2017; Stefanics et al., 2012), and congruent affective contexts, such as emotional priming pictures (Hietanen & Astikainen, 2013) and emotional scenes

(Righart & de Gelder, 2006; 2008), can increase the amplitude of N170. In addition, some studies have shown decreased amplitudes of N170 in depression patients compared with the control participants to infrequent happy and sad faces (Chang et al., 2010; for no such effect in passive oddball condition, see Ruohonen et al., 2020). Studies on the mood effects on P2 to emotional faces are rare, but one previous study (Chen et al., 2008) investigated the mood effects on P2 responses when the participants categorized emotional pictures of various content as pleasant or unpleasant. The authors observed a larger P2 amplitude difference between positive and negative pictures in sad rather than happy mood. More research is needed to understand whether sad mood affects categorization or other conscious tasks related to visual stimuli more than it affects task-irrelevant processing.

5. Limitations

There are some obvious limitations to the study. The sample size estimation was based on a medium effect size, so small effects were not observable. This might be the reason for the null results regarding mood effects on N170 and P2. In addition, we applied the full mood induction procedure about 20 min before the current experiment, and only sad music was played immediately before the current experiment to maintain the sad mood. This delay might have led to insufficient mood induction for the current experiment. However, scores for mood evaluation (VAMS) in the sad mood condition were similar immediately after the mood induction and at the beginning of the current experiment, suggesting that the delay did not remove the feeling of sadness. Finally, as discussed above, we were not able to separate the effects of facial emotion and probability of the faces on the ERPs, so it is possible that not only emotional expression, but also their lower probability affected the ERP amplitudes to emotional faces.

6. Conclusions

In sum, our findings indicate that induced sad mood impairs the featural encoding of happy faces. Our findings from the ERP recordings might have relevance to behavior, and because rapid encoding of emotional facial expressions is important for social cognition, sad mood might have consequences, especially for social perception and associated social interactions.

Declaration of interest statement

The authors declare no competing interests.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biopsycho.2023.108531.

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