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Xueqiao Li

Depressive Symptoms and Depressed Mood Affect Cognitive Processing of Emotional Information

Evidence from Psychophysiological and Behavioral Studies

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF EDUCATION AND PSYCHOLOGY

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Esitetään Jyväskylän yliopiston kasvatustieteiden ja psykologian tiedekunnan suostumuksella
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ABSTRACT

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Depression is a severe mental health disorder. Many empirical studies using experimental static stimuli, such as pictures, have reported alterations in the processing of emotional information in depression. However, the way depressed people react to dynamic emotional stimuli has not yet been researched in depth. It is also unclear how depressed mood in healthy people influence the processing of emotional information. This doctoral thesis investigates these issues. In three studies, the measurements of electrical brain activity (event-related potential (ERP)), physiological reactivity (electrodermal activity (EDA)), and behavioral responses (facial electromyography (EMG); valence rating), were applied. **Study I** investigated the cognitive and affective processing of ironic conversations in depressed and non-depressed individuals. The results showed greater brain responses (N400 and P600) to ironic than to non-ironic punchlines in both groups, indicating increased cognitive effort in interpreting ironic meanings. A right-hemisphere dominant P600 modulation to irony was found specifically in the depressed group. However, no depression-related alterations were found in facial EMG specifically related to irony. **Study II** explored the intersubject synchrony of dynamic valence ratings (i.e., the similarity of ratings) across depressed and non-depressed participants when viewing amusing, sad, and fearful movie clips. The results showed that the synchrony of valence ratings to sad movies across depressed participants was lower compared to the controls, which may reflect less stimulus-dependent processing in depression when viewing mood-congruent stimuli. **Study III** investigated how depressed mood, which was induced with sad music and statements, affected brain responses by measuring the preattentive detection of changes in facial expressions in healthy participants. The induced depressed mood affected the encoding of face structure, which was indexed by the brain's smaller amplitude of N170 differential responses in depressed mood rather than neutral mood. In sum, this dissertation shows evidence that depressive symptoms affect the cognitive processing of different types of dynamic emotional stimuli, and it also provides the first evidence of the effect of depressed mood on healthy participants' preattentive face perception.

Keywords: depressed mood, depressive symptoms, dynamic stimuli, emotional information, event-related potentials, intersubject correlation

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Li, Xueqiao
Masennusoireet ja masentunut mieliala vaikuttavat tunnepitoisten ärsykkeiden kognitiiviseen käsittelyyn: todisteita psykofysiologisista ja käyttäytymisen mittareista
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Masennus on yksi vakavista mielenterveyden häiriöistä. Monet tutkimukset ovat käyttäneet staattisia ärsykkeitä kuten kuvia ärsykkeinä ja raportoineet poikkeavuuksia tunnepitoisen tiedon prosessoinnissa masennukseen liittyen. Masentuneiden ihmisten reaktioita tunnepitoisiin dynaamisiin ärsykkeisiin kuten puheeseen tai elokuviin ei ole kuitenkaan paljoa tutkittu. On myös epäselvää, kuinka masentunut mieliala terveillä ihmisillä vaikuttaa tunnepitoisen tiedon käsittelyyn. Tämä väitöskirjatutkimus selvittää näitä asioita. Tutkimuksessa käytettiin aivojen sähköisten jännitevasteiden, fysiologisten (ihon sähkönjohtavuus) ja käyttäytymisvasteiden (kasvojen lihasaktiivisuus, valenssin arviointi) mittauksia. **Osatutkimus I** tutki ironian kognitiivista ja affektiivista prosessointia masentuneilla ja ei-masentuneilla ihmisillä. Tulokset osoittivat, että N400- ja P600-aivovasteet olivat molemmissa ryhmissä suurempia ironisiin kuin ei-ironisiin lauseisiin ilmentäen suurempaa ponnistelua ironisten merkitysten tulkintaan liittyen. P600-vaste ilmeni oikeaan aivopuoliskoon painottuneena aktiivisuutena erityisesti masennusryhmässä. Masennukseen liittyviä muutoksia ei kuinkaan löytynyt valenssiarvioissa tai kasvolihasaktiivisuudessa erityisesti ironiaan liittyen. **Osatutkimus II** selvitti yksilöiden välistä synkroniaa eli reaktioiden samankaltaisuutta valenssiarvioissa liittyen hauskoihin, surullisiin ja pelottaviin elokuvakohtauksiin. Tulokset osoittivat, että synkronia oli vähäisempää surullisiin elokuviin masentuneilla kuin kontrolleilla, mikä saattaa ilmentää vähäisempää ärsykkeisiin kytkeytyvää prosessointia masentuneilla. **Osatutkimus III** selvitti terveillä koehenkilöillä, kuinka masentunut mieliala, joka oli tuotettu surullisella musiikilla ja lauseilla, vaikuttaa aivovasteisiin, jotka mittaavat esitietoista muutoksen havaitsemista kasvon ilmeissä. Verrattuna neutraaliin mielialaan, masentunut mieliala pienensi kasvojen rakenteen koodaamiseen liittyvää N170-vasteen amplitudia. Kokonaisuutenaan tämän tutkimuksen tulokset osoittavat, että masennusoireet vaikuttavat erityyppisten dynaamisten tunnepitoisten ärsykkeiden kognitiiviseen prosessointiin. Tutkimus tarjoaa myös ensimmäisiä todisteita masentuneen mielialan vaikutuksesta terveiden henkilöiden esitietoiseen kasvojen havaintoon.

Avainsanat: aivojen herätevasteet, dynaamiset ärsykkeet, yksilöiden välinen korrelaatio, masennusoireet, masentunut mieliala, tunnepitoinen tieto

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LIST OF ORIGINAL PUBLICATIONS

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II Li, X., Zhu, Y., Vuoriainen, E., Ye, C., & Astikainen, P. (2021). Decreased intersubject synchrony in dynamic valence ratings of sad movie contents in dysphoric individuals. *Scientific Reports*, *11*, 14419.

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Taking into account the instructions given and comments made by the co-authors, the author of this thesis planned the experiments, collected the data, conducted data analysis, and wrote the manuscripts of the three studies.

FIGURES

TABLES

CONTENTS

1 INTRODUCTION

Emotional information processing, such as the perception and interpretation of environmental stimuli, is important for human survival, social interaction, and communication. For instance, perception of human faces can help us identify other individuals, and inform us of other people's opinions, intentions, and emotional states. In mood disorders, such as depressive disorder, deficits and biases in the processing of emotional information (Beck, 1967, 2008) that could predispose individuals to depressive episodes and maintain depression have been observed.

Depression is a severe mental health disorder that involves both affective (e.g., persistent lowering of mood, reduced interests, hopelessness, and self-blame) and somatic (e.g., pain in the body, weakness, changes in sleep or appetite) symptoms, based on the guidance from the International Statistical Classification of Diseases and Related Health Problems, 11th Revision (ICD-11). Globally, more than 300 million people are estimated to suffer from depression (World Health Organization (WHO), 2010). In Finland, depression is one of the main causes of disability from work, which results in substantial economic burdens to society.

Depressed individuals possess deficits and biases in processing emotional information, which are mainly reflected in selective attention to negative stimuli, ruminative thoughts about the self and surroundings, and difficulties in emotion regulation (Foland-Ross & Gotlib, 2012; Gotlib & Joormann, 2010; LeMoult & Gotlib, 2019; Peckham et al., 2010). Previous empirical studies have mainly explored these alterations in information processing in depression with experimental static stimuli, such as pictures of facial expressions (Chang et al., 2010; Ruohonen et al., 2020; Xu et al., 2018; Zhang et al., 2016; Zhao et al., 2015), other types of emotional pictures (Caseras et al., 2007; Eizenman et al., 2003), and written words (Shestyuk et al., 2005; Siegle et al., 2001, 2002). Many studies have reported that depressive individuals exhibit a mood-congruent bias toward sad faces (Dai et al., 2016; Dai & Feng, 2012; Gotlib et al., 2004; Joormann & Gotlib, 2007), negative pictures (Caseras et al., 2007; Eizenman et al., 2003), and negative words (Koster et al., 2005; Siegle et al., 2002), as reflected by pronounced responses or sustained attention to negative stimuli compared to neutral stimuli.

Recently, researchers in the field of cognitive neuroscience have been increasingly in favor of naturalistic settings in which dynamic stimuli (e.g., narratives, music, and movie clips) that better represent the real world compared to static stimuli are applied (Chang et al., 2015; Hasson, 2004; Hasson et al., 2008; Hasson & Honey, 2012; Jääskeläinen et al., 2008; Kauppi et al., 2010; Lahnakoski et al., 2014). Furthermore, there has been interest in investigating individual differences in behavioral and psychophysiological responses, rather than only group averages. These approaches, including applying naturalistic settings and dynamic stimulus conditions and investigating variances across participants, could supplement the current understanding of cognitive and affective alterations in the processing of emotional information related to depression.

On the other hand, although the processing of emotional information, especially emotional face processing, has been investigated widely in depressed individuals, less is known about how depressed mood in healthy people influence the processing of emotional information. Sustained depressed mood is a dominant symptom of depression (ICD-11). It is possible that the responses of healthy individuals in depressed mood to emotional stimuli are similar to those of depressive patients. Importantly, results from investigations of the effects of depressed mood on the processing of emotional information in healthy individuals may inform future studies exploring biomarkers for diagnosing depressive disorder. For instance, if healthy participants in depressed mood show similar alterations in the processing of emotional information to depression patients, these responses cannot be considered biomarkers for diagnosing depressive disorder.

This doctoral thesis aims to deepen the current understanding of the way people with an elevated number of depressive symptoms react to emotional stimuli. Instead of using experimental static stimuli, as in many previous depression-related studies, the research applies dynamic auditory and visual stimuli (i.e., spoken conversations and movie clips, respectively). In addition, the research explores whether healthy people have similar brain responses to changes in facial expressions in induced neutral and depressed moods. Three studies that contribute to the doctoral thesis have been conducted. **Study I** focuses on the effects of depressive symptoms on the cognitive processing of and emotional reactions to spoken ironic conversations. **Study II** investigates the effects of depressive symptoms on the continuous valence rating of emotional movie clips by comparing group averages (depressed participants and controls) and variances across participants within each group. **Study III** explores how an induced depressed mood affects brain responses to rare changes in emotional faces in healthy participants compared to a neutral mood.

1.1 Irony comprehension and irony-related emotional reactions

Irony is used in people's daily conversations to convey implicit meanings in social communications. Irony is usually elicited from a contrast between what people literally express and what they intend to express (Grice, 1975). Compared to speaking directly, ironic expressions aim to achieve implied communicative goals and induce certain emotions (Colston, 2009; Dews et al., 2009; Dews & Winner, 2009; Gibbs et al., 2014). For example, imagine that you are traveling in Lapland (the northernmost part of Finland) for the Christmas holidays. This is the last night of the trip, and you are waiting outside for your last chance to see the northern lights. The sky is cloudy, and it starts to snow. Your friend says, "It's such perfect weather to see auroras." This remark, which opposes the real scenario, is a good demonstration of an ironic comment.

There are different theories concerning irony comprehension, and the main distinction among them is whether the literal meaning of the utterance is supposed to be analyzed when comprehending irony (Gibbs & Colston, 2007). For instance, the direct access view suggests that the processing of irony could be similar to the processing of literal utterances, as the implied meanings of irony could be directly comprehended without necessarily analyzing the literal meaning (Gibbs, 2002). On the contrary, the two-stage model proposes that for irony comprehension, it is necessary to obtain both literal and ironic meanings (Giora, 2003; Giora & Fein, 1999; Grice, 1975). Empirical evidence has mostly supported the two-stage model and has shown that irony requires extra effort to process compared to literal utterances. For example, previous studies have reported that participants spent more time reading ironic comments than literal ones (Giora et al., 2009; Schwoebel et al., 2000). Furthermore, by observing participants' eye movements while reading ironic and non-ironic sentences, previous studies have found longer fixation times on the ironic than non-ironic target words/phrases, and that participants were more likely to look back to the ironic sentences than non-ironic ones (Filik et al., 2014; Filik & Moxey, 2010; Kaakinen et al., 2014).

Studies using the event-related potentials (ERPs) method have also suggested that additional efforts are required to comprehend irony compared to literal utterances (Balconi & Amenta, 2008; Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014; Regel et al., 2011, 2014; Spotorno et al., 2013). ERPs are averaged electroencephalography (EEG) brain responses time locked to the onset of stimulus presentation. Time-sensitive ERPs provide possibilities for measuring the different processing stages of irony comprehension. Two ERP components, N400 and P600, are particularly relevant for investigating irony comprehension (Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014).

The N400 is a negative polarity ERP component that occurs between approximately 200 and 600 ms after the onset of a stimulus and is usually observed at the centro-parietal electrode sites (Kutas & Federmeier, 2011; Lau et al., 2008). N400 has been suggested to be associated with difficulties in retrieving stimulus-related information from memory (Brouwer et al., 2012) or the inability to fit semantic violations within the sentence context (Kutas & Federmeier, 2011; Lau et al., 2008). In relation to the processing of nonliteral language, N400 effects have been observed for the comprehension of, for example, humor (Coulson & Kutas, 2001; Feng et al., 2014; Marinkovic et al., 2011) and metaphor (Coulson &

Van Petten, 2002). Previous studies have also demonstrated a larger N400 amplitude for ironic stimuli compared to non-ironic stimuli (Baptista et al., 2017; Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014). For an absence of N400 in irony comprehension, see Balconi and Amenta (2008) and Regel et al. (2011, 2014). The N400 modulation of ironic stimuli may reflect additional cognitive effort when encountering semantic violations in a literal statement (Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014).

The P600 is a positive polarity ERP component peaking approximately 600 ms after stimulus onset at the centro-parietal electrode sites (Bornkessel-Schlesewsky & Schlesewsky, 2008). Initially, the P600 was reported to be triggered by grammatically incorrect anomalies and to reflect efforts on syntactic reanalysis (Gouvea et al., 2010; Osterhout & Holcomb, 1992). However, P600 modulation by semantic violations has also been observed, which is suggested to involve continued analysis to resolve semantic conflicts in language comprehension (Nieuwland & Van Berkum, 2005; Sanford et al., 2011). Regarding irony comprehension, previous studies have found a larger P600 amplitude in response to ironic than non-ironic stimuli (Filik et al., 2014; Regel et al., 2011, 2014; Spotorno et al., 2013), which was interpreted as the participant making cognitive efforts to interpret the hidden meaning of irony (Regel et al., 2011, 2014).

Regarding irony-related emotional reactions, the results are inconsistent. Irony could be perceived as positive by the receiver, viewed as more humorous and amusing than literal statements (Akimoto et al., 2014; Calmus & Caillies, 2014; Dews et al., 2009; Dynel, 2014; Matthews et al., 2010), and may reduce the receiver's negative feelings (Dews & Winner, 2009; Thompson et al., 2016). On the other hand, some studies have found that irony increases negative feelings in the receiver (Akimoto et al., 2014; Leggitt & Gibbs, 2000; Toplak & Katz, 2000).

1.2 Possible alterations in irony comprehension and irony-related emotional reactions in depression

In depression, alternations have been found in the comprehension of nonliteral language, such as humor stories (Uekermann et al., 2008), but irony comprehension has not been investigated before. A study by Uekermann et al. (2018) showed that deficits in mentalizing (e.g., the ability to reason other's intentions or thoughts) and executive functions (e.g., inhibition of a dominant response) in depressive participants were associated with their altered humor processing. Previous studies have provided evidence that deficits in mentalizing are linked to alterations in irony comprehension in schizophrenia and schizotypal personality disorder (Del Goleto et al., 2016; Herold et al., 2018; Varga et al., 2013). The processing of irony may also be altered in depression because of depressed individuals' impairments in mentalizing (Bora & Berk, 2016). In addition, verbal fluency and verbal memory, which are particularly relevant to irony comprehension (Gaudreau et al., 2015; Spotorno et al., 2013), have also been found to be impaired in depression (Basso & Bornstein, 1999; Henry & Crawford, 2005). Therefore, based on previous evidence of impairments in irony-related cognitive function (e.g., executive function, mentalizing, verbal fluency, and verbal memory) in depression, I hypothesized that irony comprehension could be altered in people with depressive symptoms.

In addition to the possible alternations in irony comprehension, emotional reactions to ironic stimuli may also be affected by depressive symptoms. Depressive individuals have been suggested to have a mood-congruent bias in the processing of emotional information (e.g., pronounced responses/attention to negative stimuli compared to neutral stimuli) (Foland-Ross & Gotlib, 2012; Gotlib & Joormann, 2010; Peckham et al., 2010). Blunted responses to emotional stimuli have also been found in depression (Benning & Oumeziane, 2017; Bylsma et al., 2008), which are reflected by, for instance, less intensive self-reported emotions to affective films (Rottenberg et al., 2002, 2005), and less facial muscle reactivity to emotional images or facial expressions (Gehricke & Shapiro, 2000; Wexler et al., 1994) in depressed individuals compared to non-depressed participants. Based on these previous findings, I assumed that irony-related emotional responses may differ between depressed and non-depressed participants.

1.3 Intersubject neural synchronization to dynamic stimuli

When investigating the processing of emotional information in depression, many studies have presented participants with static stimuli (Gotlib & Joormann, 2010; Peckham et al., 2010). The stimuli are usually presented in a highly controlled paradigm to isolate the targeted cognitive or emotional processes. However, in real life, people encounter dynamic and multimodal stimuli in complex circumstances, and they respond to the stimuli naturally (i.e., viewing visual stimuli with free eye movements rather than fixating on the center of the screen). Thus, it is of great interest to investigate depression-related alterations in the processing of emotional information by applying dynamic stimuli in naturalistic settings.

Recent research in the field of neuroimaging has increasingly applied movies as stimuli to investigate participants' reactions to emotional information, as movies are dynamic and closer to the real world than static pictures, and sounds and movies can evoke strong emotions (Jääskeläinen et al., 2021). Furthermore, the similarity of responses to emotional stimuli between participants, also called intersubject synchrony, has gained increasing interest, and the intersubject correlation (ISC) approach (Hasson, 2004; Nummenmaa et al., 2018) has been increasingly applied. This approach allows one to investigate the correlation of dynamic responses across individuals, for example, when they attend to the same dynamic scenes or events. Previous functional magnetic resonance imaging (fMRI) studies have observed similar brain activity patterns in response to the movies, reflected by high ISC in multiple cortical areas across healthy individuals (Hasson, 2004; Jääskeläinen et al., 2008; Kauppi et al., 2010; Nummenmaa et al., 2012). High ISC of magnetoencephalography (MEG) and electroencephalography (EEG) activity has also been found in healthy participants during movie watching (Chang et al., 2015; Dmochowski et al., 2012; Ki et al., 2016; Lankinen et al., 2014; Lankinen et al., 2018; Maffei, 2020; Poulsen et al., 2017). Previous neuroimaging studies suggest that the similarity of brain activity patterns across healthy participants could be modulated by, for instance, valence and arousal that participants experience under the stimuli (Nummenmaa et al., 2012), similarity in participants' interpretations of the stimuli (Nguyen et al., 2019), and the attention and emotional involvement that participants allocate to the stimuli (Dmochowski et al., 2012; Ki et al., 2016).

Individuals with neuropsychiatric disorders have shown a lower ISC of neural responses elicited by natural stimuli compared to healthy participants. For instance, compared to neurotypical controls, participants with autism exhibit weaker temporal synchronization of fMRI responses in multiple cortical areas while watching movies (Hasson et al., 2009; Salmi et al., 2013). Heterogeneous brain activation patterns in autistic participants suggest widespread neuronal dysfunction and social comprehension deficits in autistic individuals (Byrge et al., 2015). Less synchronized brain activation patterns (fMRI response) were also observed in participants with schizophrenia compared to controls while viewing silent video clips of advertisements (Yang et al., 2020) and movie clips of humorous scenes (Tu et al., 2019). Tu et al. (2019) found that participants with schizophrenia exhibited a lower ISC, mainly in the fronto-parietal areas, which may be caused by dysfunction in information integration, lack of appreciation of humorousness, and deficits in the cognitive processing of humor. Concerning the present thesis, fewer synchronized brain activity patterns have also been reported in adults (Guo et al., 2015) and adolescents (Gruskin et al., 2020) with major depressive disorder (MDD) compared to the control participants while viewing emotional movies. Guo et al. (2015) found that depressed participants compared to non-depressed controls exhibited weaker temporal synchronization of fMRI responses in multiple brain regions related to sensation, emotion, and attention while watching a negative emotional movie. Gruskin et al. (2020) observed a negative relationship between depressive symptoms and how similar adolescents' fMRI responses were to emotional movies.

To the best of my knowledge, the intersubject synchrony of behavioral ratings of dynamic stimuli has rarely been studied, especially in participants with depressive symptoms (for synchronization of subjective emotion rating for music in healthy participants, see Sachs et al. (2020)). Previous behavioral studies of depression have mainly focused on group averages and compared, for example, behavioral ratings of emotional stimuli (i.e., emotional valence, experienced arousal) (Dunn et al., 2004; Kaviani et al., 2004; Rottenberg et al., 2002, 2005). It is unknown whether depressed individuals' dynamic evaluations of emotional stimuli are less synchronized than those of control participants.

1.4 ERPs to facial expressions

For humans, faces are common targets for social attention since they convey emotions among other socially relevant information. Previous findings have shown that facial expressions can modulate visual ERP components, such as P1, N170, and P2 (Batty & Taylor, 2003; Bentin et al., 1996); however, for no modulation of N170, see Ashley et al. (2004) and Eimer et al. (2003). P1 is a positive polarity deflection over the left and right occipital areas, which peaks around 100 ms after stimulus onset and reflects the encoding of low-level visual features (for faces, see Batty and Taylor (2003), Itier and Taylor (2002), Rossion and Caharel (2011), and Taylor (2002)). Following P1, N170 is a negative polarity ERP response to visual stimuli, elicited approximately 170 ms after stimulus onset at the left and right parieto-occipital electrodes. A larger N170 amplitude to faces than to non-face objects has been repeatedly observed (Bentin et al., 1996; Rossion, 2014; Rossion & Jacques, 2008). Previous studies have suggested that N170 could index the automatic structural encoding of faces (Batty & Taylor, 2003; Bentin et al., 1996; Blau et al., 2007; Hinojosa et al., 2015; Krombholz et al., 2007; Leppänen et al., 2007). P2 follows N170, and peaks approximately 200 ms after stimulus onset in the posterior region (Schweinberger & Neumann, 2016). Previous studies have suggested that the modulation of P2 is related to the basic features of visual stimuli and stimulus salience (Carretié et al., 2001; Latinus & Taylor, 2006; Schweinberger & Neumann, 2016).

Preattentive change detection in facial expressions is crucial for social interactions, since rapid and unexpected changes of expressions may deliver important social-emotional information. Preattentive change detection in facial expressions can be investigated with ERPs in a passive oddball paradigm (Astikainen et al., 2013; Astikainen & Hietanen, 2009; Kimura et al., 2012; Kreegipuu et al., 2013; Liu et al., 2016; Stefanics et al., 2012; Susac et al., 2010; Zhao & Li, 2006). In the passive oddball paradigm, one facial expression, typically a neutral expression, is presented repeatedly as a "standard" stimulus. One or more other facial expression(s) are "deviant" stimuli that rarely and randomly replace the standard stimulus. While facial pictures are presented to the screen in front of a participant, the participant is instructed to engage in another cognitive task, such as an auditory counting/discrimination task (Astikainen & Hietanen, 2009; Zhao & Li, 2006), or a visual counting/detection task (Kreegipuu et al., 2013; Stefanics et al., 2012; Susac et al., 2010).

Brain responses to deviant stimuli reflecting change detection can be explored using visual mismatch negativity (vMMN), an ERP reflecting preattentive change detection. The vMMN has been found to occur at different latencies, and sometimes as modulation of multiple conventional components, such as P1, N170, and P2, at latency ranges from 70 ms to 360 ms post-stimulus (Astikainen et al., 2013; Astikainen & Hietanen, 2009; Chang et al., 2010; Kimura et al., 2012; Li et al., 2012; Stefanics et al., 2012; Susac et al., 2004; Xu et al., 2018; Zhao & Li, 2006). The MMN has been associated with prediction error signals in the framework of predictive coding theory (Friston, 2005; Garrido et al., 2009; Wacongne et al., 2012); specifically, for the vMMN, see Stefanics et al. (2015). According to predictive coding theory, the brain makes constant predictions about upcoming input based on observed regularities and then adjusts its prediction models according to sensory feedback (Friston, 2005; Rao & Ballard, 1999). MMN responses have been interpreted in this context as error signals arising from a conflict between prediction and sensory feedback (Friston, 2005; Wacongne et al., 2012).

1.5 Depression-related alterations and effects of induced mood on face processing

Many behavioral studies have investigated depressed participants' responses to emotional facial expressions, and it has been suggested that individuals with depressive symptoms show a negative bias for facial expression processing; for a review, see Delle-Vigne et al. (2014). For instance, one previous behavioral study found that both currently and formally depressed participants showed preferred attention to sad faces in a dot-probe task (Joormann & Gotlib, 2007). Depressed individuals are also more likely than non-depressed participants to perceive neutral faces as sad (Gollan et al., 2008). Other behavioral studies have revealed depression-related deficits in the identification and recognition of facial expressions (i.e., happy faces: LeMoult et al. (2009), neutral faces: Leppänen et al. (2004)).

This bias is also reflected in early automatic brain responses, where ERP amplitudes are found to be larger for sad expressions compared to neutral expressions in the depression group (e.g., larger P1 amplitudes to sad faces: Dai & Feng (2012) and Zhang et al. (2016); larger N170 amplitudes to sad faces: Dai et al. (2016) and Zhao et al. (2015)). Concerning the preattentive change detection of facial expressions, the brain responses to deviant facial expressions are known to be altered in depression and several other psychiatric and neurodevelopmental disorders (Kremláček et al., 2016). Sometimes, alterations in ERP modulations in depressive samples are observed as increased response amplitudes. For example, in depressed participants, larger responses to sad faces have been reported, reflecting negative bias for sad faces in automatic brain responses (larger P1 amplitudes to sad deviant faces: Ruohonen et al. (2020); larger M300 amplitudes to sad deviant faces: Xu et al. (2018)). Sometimes, smaller or absent vMMN amplitudes are observed in depression (Chang et al., 2010; Xu et al., 2018), which probably reflects impaired change detection in facial expressions.

Recent evidence in depression-related studies has suggested that the mood-congruent bias toward sad faces could be state-dependent since brain activity in response to sad faces is reduced after symptom reduction (for an ERP study, see Ruohonen et al. (2020), for fMRI studies, see Fu et al. (2008) and Victor et al. (2010))

and correlates with the number of depressive symptoms (Wu et al., 2016) in clinical depression. Among the depressive symptoms (e.g., fatigue, reduced interest, disturbed sleep, thoughts of suicide), a sustained depressed mood is one of the primary symptoms (WHO, 2010). Therefore, it is possible that the ERP responses to the emotional faces of healthy participants in depressed mood are similar to those of depression patients.

To induce a certain momentary mood for healthy participants in a lab environment, emotional films (Curby et al., 2012), images (Xie & Zhang, 2016), music (Bouhuys et al., 1995; Chen et al., 2008), or statements (Clark, 1983; Velten, 1967) are usually applied. Exiting evidence suggests that induced mood can influence individuals' attention to their own thoughts and feelings (Panayiotou et al., 2007; Sedikides, 1992; Silvia & Abele, 2002), recognition of word emotionality (Sereno et al., 2015), and responses to emotional pictures (Chen et al., 2008). Mood can also affect people's performance in face identity recognition. For instance, when pictures of neutral faces were presented, healthy participants in negative mood showed reduced holistic face processing, as well as accuracy for face identity recognition (Curby et al., 2012; Xie & Zhang, 2016).

It is not clear whether healthy individuals show different ERPs to facial expressions when in depressed and neutral moods. A previous behavioral study found that when healthy participants were in a depressed mood, they reported perceiving sadder emotions in response to ambiguous faces and less happy feelings in clear faces, showing that an induced depressed mood influences healthy individuals' judgment of emotional facial expressions (Bouhuys et al., 1995). For mood effect on preattentive change detection, a previous study reported that experimentally induced negative mood, compared to neutral and positive mood, reduced auditory MMN amplitudes regardless of deviant sound features (intensity and duration) (Pinheiro et al., 2017). Taken together, depressed mood may disrupt healthy participants' preattentive change detection in facial expressions.

1.6 Aims of the research

This thesis aims to advance the present knowledge of how healthy and depressive people react to emotional stimuli. Different types of ecologically valid stimuli (spoken conversations, movies, facial expressions) were applied, which could, to some extent, mimic the activity occurring during real-world circumstances and provide a deeper understanding of the effects of depressive symptoms and depressed mood on the processing of emotional information.

Study I investigated possible differences between depressed participants (participants who had elevated amounts of current depressive symptoms) and non-depressed controls in irony-related cognitive processing and emotional reactions. Spoken conversations in which two people were commenting on a picture were presented to imitate the natural occurrence of irony in real-life experiences. Compared to previous studies, where the keywords were always allocated at the end of the sentences (Filik et al., 2014; Regel et al., 2011, 2014), the keywords in **Study I** were less predictable since they were presented in different positions. Following previous irony-related studies, ERPs (N400 and P600) were applied to explore cognitive processes in irony comprehension (Balconi & Amenta, 2008; Baptista et al., 2017; Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014; Regel et al., 2011, 2014; Spotorno et al., 2013). Facial electromyography (EMG) was used to measure emotional reactions related to irony (Thompson et al., 2016) from the zygomaticus major muscle (cheek region) and the corrugator supercilii muscle (brow region), which could reflect automatic facial reactivities of smiling and frowning, respectively (Boxtel, 2010; Dimberg & Lundquist, 1990). On a separate day, behavioral evaluations of the stimuli for congruency and valence were also recorded. For ERP responses, decreased P600 amplitudes in response to ironic stimuli were expected to be observed in the depressed group compared to the control group. Schizotypal personality disorder has been reported to decrease P600 amplitudes in irony comprehension due to deficits in mentalizing (Del Goleto et al., 2016). Depression may show similar decreased P600 responses since the depressed participants had alterations in mentalizing as well (Bora & Berk, 2016). Based on previous findings demonstrating negative bias in processing emotional information and low reactivity to emotional stimuli in depression (Beck, 1967, 2008; Bylsma et al., 2008; Gotlib & Joormann, 2010), more negative valence ratings for the ironic stimuli in the depressed than in the control group were expected. Compared to the control group, facial EMG reactivity was hypothesized to be smaller between the ironic and non-ironic stimuli in the depressed group.

In **Study II**, dynamic valence ratings of amusing, sad, and fearful movie clips were measured in depressed and non-depressed participants to investigate the effects of depressive symptoms on intersubject synchronization in the conscious processing of emotional stimuli. Sad and fearful movie clips were selected to investigate whether participants with depressive symptoms, compared to non-depressed participants, had lower synchrony for negative stimuli in general or only for mood-congruent stimuli (sad movie clips). In addition, amusing movie clips were applied to explore whether depressed participants also had decreased synchrony for positive stimuli. For the first time, the ISC of the dynamic valence ratings of emotional movie contents was explored in both depressed and healthy control groups. Previous studies using neuroimaging methods have reported lower ISC of brain responses in depression than non-depressed controls (Gruskin et al., 2020; Guo et al., 2015). Thus, a lower ISC of valence ratings was expected in the depressed group than in the control group. Furthermore, due to the mood-congruent (sad) attentive bias in processing emotional information in depression (Ruohonen et al., 2020; Xu et al., 2018; Zhang et al., 2016; Zhao et al., 2015) and difficulties in disengagement from sad stimuli (Gotlib & Joormann, 2010), sad movie clips may elicit less stimulus-oriented reactions but more self-related ruminations in the depressed group than in the control group. Therefore, depressed participants were expected to have a lower valence rating of ISC for sad movie clips. Previous study has suggested that emotional arousal of stimuli is associated with the ISC of brain responses to movies (Nummenmaa et al., 2012). That is, stimuli rated as high arousal could direct individuals to focus on similar surrounding features, and thus enhance the ISC of participants' fMRI responses (Nummenmaa et al., 2012). Hence, electrodermal activity (EDA), which measures the electrical conductance from the skin of the hand and can reflect an individual's emotional arousal based on sweat secretion (Dawson et al., 2016), was also measured when the participants viewed the movies with the aim of supporting the interpretation of the ISC results.

Study III examined the preattentive change detection of facial expressions in healthy individuals reflected by ERPs and the effects of induced depressed mood on these responses. Participants were induced into neutral and depressed moods on two separate days. Neutral, sad, and happy faces were presented in a passive oddball paradigm, where neutral standard faces were randomly replaced by sad and happy deviant faces. Differential responses (responses to deviant faces minus responses to standard faces, corresponding to the vMMN) of P1, N170, and P2, which reflect different stages of stimulus processing (Astikainen & Hietanen, 2009; Chang et al., 2010; Stefanics et al., 2012; Zhao & Li, 2006), were compared between experimentally induced depressed mood and neutral mood. Previous studies have reported reduced auditory MMN to deviant sounds when healthy participants were in depressed mood (Pinheiro et al., 2017) and decreased N170 and P2 amplitudes to deviant faces in depression (Chang et al., 2010). Therefore, it was hypothesized that depressed mood could have a similar effect on healthy participants' change detection of faces.

2 METHODS

2.1 Participants

In all the studies, native Finnish speakers were recruited as volunteers through university email lists (University of Jyväskylä) and by advertisement flyers distributed around Jyväskylä. In **Study I** and **II**, participants were divided into two groups: 1) a depressed group[1] in which participants had elevated amounts of current depressive symptoms, and 2) an age-and gender-matched control group without any psychiatric diagnosis. In **Study III**, only one group of participants was recruited. The sample size for each study was estimated based on a priori power analysis implemented using G*Power 3 (Faul et al., 2007).

For all three studies, the inclusion criteria were right-handedness, normal, or correct-to-normal vision, normal hearing ability, age range from 18 to 40 years, and no self-reported history of brain damage, neurological disease, or drug or alcohol abuse. Participants with current or previous psychiatric disorders and symptoms, except for depression and anxiety symptoms in the depressed group in **Study I** and **II,** were excluded. For **Study I** and **II,** participants with current scores of no less than 13 in Beck's Depression Inventory-II (BDI-II) (Beck et al., 1996) were included in the depressed group. In the control groups of **Study I** and **II**, and in **Study III,** participants all had BDI-II scores of less than 10. In **Study III**, pregnant or breastfeeding females were also excluded from the experiments because of the possibility of hormonal changes would affect mood induction. In addition, participants who did not successfully elicit depressed mood after the mood induction procedure were excluded from the final sample of **Study III**.

After applying the exclusion criteria (e.g., the inefficiency of mood induction in **Study III**) and removing participants with excessive artifacts in the psychophysiological data, there were 38 adult participants (17 depressed

[1] In the original papers of **Study I** and **II**, we used term dysphoric group.

participants and 21 controls) in the final sample of **Study I**, 43 adult participants (21 depressed participants and 22 controls) in **Study II**, and 22 healthy adults in **Study III**. The demographics of the participants in the three studies are reported in Table 1.

TABLE 1 Demographic information of participants and methods for each study.

Study	Participants	Measure	Statistics
I	DEP (n = 17) • Age: M = 24.8 ± 3.7 years • Gender: Male = 3, Female = 14 • BDI-II: M = 23.7 ± 6.6 CTRL (n = 21) • Age: M = 23.5 ± 3.2 years • Gender: Male = 6, Female = 15 • BDI-II: M = 2.5 ± 2.6	• Facial EMG • EEG • Accuracy and response time of congruency detection • Valence rating • Humor Styles Questionnaire • Cognitive tests	• Multilevel model analysis • Repeated measures ANOVA • T-tests • Pearson's correlation • FDR • Repeated measures ANCOVA • Principal component analysis • Linear regression analysis
II	DEP (n = 21) • Age: M = 30.3 ± 7.4 years • Gender: Male = 7, Female = 14 • BDI-II: M = 29.4 ± 8.0 CTRL (n = 22) • Age: M = 26.7 ± 6.5 years • Gender: Male = 4, Female = 18 • BDI-II: M = 2.0 ± 1.8	• EEG (not reported here) • Continuous valence rating • EDA	• Repeated measures ANOVA • T-tests • Bonferroni correction • Repeated measures ANCOVA • Pearson's correlation • Spearman's rank correlation • ISC • FDR
III	N = 22 • Age: M = 26.6 ± 4.4 years • Gender: Male = 10, Female = 12 • BDI-II: M = 2.05 ± 2.17	• EEG • VAMS	• Repeated measures ANOVA • T-tests

DEP = depressed participants, CTRL = control participants, M = mean, BDI-II = Beck's Depression Inventory (2nd Ed.), FDR = False discovery rate, ANOVA = Analysis of variance, ANCOVA = Analysis of covariance, VAMS = Visual Analog Mood Scale

2.2 Research ethics

The research protocols for all three studies followed the Declaration of Helsinki. Ethical approvals from the ethical committee of the University of Jyväskylä were received before participant recruitment. All the participants volunteered for the studies, and they were allowed to withdraw their attendance at any time without any negative consequences. Written informed consent was obtained from all participants prior to the experiment. The collected psychophysiological and behavioral data were anonymized and saved on the University of Jyväskylä server, to which only the research group has access. Questionnaires and the results of cognitive tests, which were on paper, were also stored anonymously and locked in storage space at the University of Jyväskylä. The personal information, including the participants' contact information and their corresponding experimental identification, was secured in an encrypted file on the University of Jyväskylä server and destroyed after data collection. Raw and preprocessed anonymized data, including the participants' questionnaire information and psychophysiological and behavioral responses, and analysis code in all three studies are provided to the research community upon reasonable request. Due to the copyright issue, only the stimulus materials in **Study I** can be shared, whereas the stimulus materials in **Study II** and **III** cannot be redistributed.

2.3 Stimuli and procedure

In **Study I**, stimuli were spoken dyadic conversations combined with contextual pictures. Each conversation, including an introductory sentence and a commenting sentence, was spoken by two male and two female Finnish speakers with neutral intonation. In the commenting sentences, positive (50%) and negative (50%) valence keywords were assigned to different positions. The contextual pictures showing real-life scenes were collected from the internet and the database of the International Affective Picture System (IAPS) (Lang et al., 1999). All the pictures were color ones with a resolution of 1024 × 768 pixels. The same conversation was presented twice with the pictures: once with a picture that brought a congruent (non-ironic) context to the conversation and once with a picture that provided an incongruent (ironic) context. This setting allowed the responses to be directly compared between the same commenting sentences (non-ironic versus ironic condition), where the stimuli's physical features, such as positions of punchlines, could be the same. In total, 90 trials for non-ironic and 90 trials for ironic conditions were presented to the participants. All the trials were separated into four 45-trial blocks and presented in a pseudo-random order, with a restriction that there were at least 45 other conversations presented between two of the same conversations, which was set to avoid immediate repetitions.

In **Study II**, seven amusing, five sad, and six fearful movie clips without sound or captions were selected from the database of a previous study (Schaefer et al., 2010). The movie clips were divided into three blocks according to their emotional categories, and for each block, the duration of the presentation was about 17 minutes. The movie clips were displayed randomly within each block, and the blocks of each emotion were presented in a counterbalanced order between the participants. Before each movie clip, a written recap was shown on the screen, which introduced the plot of the movie to the participants. The movie clips were shown in color with a resolution of 768 × 540 pixels.

In **Study III**, in accordance with a previous study (Robinson et al., 2012), there were 60 Finnish one-sentence mood statements (Velten, 1967) and one piece of music in each neutral and sad condition to induce the target mood. Every statement was displayed on the screen for 15 seconds, and the music continued playing until the end of the mood induction procedure, which lasted 15 minutes. For the unattended facial expression task, the sad, happy, and neutral faces of six males and six females were chosen from the Karolinska Directed Emotional Faces (KDEF) stimulus set (Lundqvist et al., 1998). The faces were converted into gray-scale with a resolution of 209 × 283 pixels and were presented at a visual angle of 3.03° × 4.11°. A gray oval frame covered the facial image to present the inner regions of the faces. The faces were presented in a passive oddball condition and in pseudo-random order: sad and happy "deviant" faces (10% for each) were rarely interspersed with neutral "standard" faces (80%), and there were at least two standard faces between consecutive deviant faces. The facial identity in the facial images changed from trial to trial. In total, 960 neutral standard faces and 120 sad and 120 happy deviant faces were presented.

In **Study I** and **III**, audio stimuli (spoken conversations in **Study I** and emotional music in **Study III**) were played via a ceiling loudspeaker above the participants. In all three studies, visual stimuli (contextual pictures in **Study I**, movie clips in **Study II**, and emotional statements and facial expressions in **Study III**) were presented on a 23-inch screen (Asus VG236H, 1920 × 1080 pixels) situated approximately 1 m in front of the participants. For all of the studies, the stimuli were presented using E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA, USA). During the measurements of the three studies, the participants were seated on a chair in a soundproofed and electricity-shielded room.

For all three studies, participants were instructed to fill out the BDI and Depression, Anxiety, Stress Scale (DASS) (Lovibond & Lovibond, 1995; Lovibond & Lovibond, 1996) before the experiment started on the first measurement day. In **Study I** and **II**, every participant attended psychophysiological and behavioral measurements on two separate days. On the first measurement day of **Study I** and **II**, participants were instructed to sit still in a relaxed position and concentrate on the stimuli without performing any tasks. On the second measurement day in **Study I**, participants were asked to evaluate half of the stimuli that were presented on the first measurement day, while in **Study II**, participants watched and continuously rated the movie clips in the same order as in the first day's recordings. In **Study I**, after the psychophysiological measurement, participants completed a set of cognitive tests. After the behavioral measurement in **Study I**, the participants filled out the Humor Style Questionnaire (Martin et al., 2003). In **Study III**, participants attended on two days to induce neutral mood and depressed mood separately. The order of mood induction was counterbalanced between the participants. The procedure for each measurement day was the same, which included the mood induction procedure, facial emotion recognition task (not reported in **Study III**), and unattended facial expression task. During the mood induction procedure, participants were asked to focus on the stimuli and try to induce the target mood. During the unattended facial expression task, the participants were instructed to concentrate on a calculation task in their minds to distract the participants' attention away from the presented facial expressions in the center of the visual field.

2.4 Psychophysiological data acquisition and preprocessing

For all three studies, continuous psychophysiological signals (**Study I**: facial EMG and EEG data; **Study II**: EDA data; **Study III**: EEG data) were measured with a NeurOne system (Bittium Biosignals Ltd., Kuopio, Finland). In **Study I**, facial EMG responses were recorded with two disposable bipolar electrode pairs (Ag/AgCl). The electrode pairs, which had 0.5 cm distance between them, were pasted on the right side of the participant's face on two regions: the corrugator supercilia muscle region and the zygomaticus major muscle region. In **Study II**, EDA data were measured with two disposable isotonic gel electrodes (Ag/AgCl, EL507, Biopac Systems, Inc.). The two electrodes were placed on the participant's thenar eminence (area below the first digit) and hypothenar eminence (area below the fourth digit) on the left palm. A galvanic skin conductance module (Brain Products, Gilching, Germany), applying a 0.5 V amplitude constant current source, was connected between the two electrodes and the NeurOne amplifier. In **Study I** and **III**, EEG signals were collected continuously from 128 electrodes mounted on a HydroCel Geodesic Sensor Net (Electric Geodesic Inc., USA). During the recording, the vertex electrode (Cz) was applied as the reference electrode. Facial EMG responses in **Study I** and EEG signals in **Study I** and **III** were measured in AC mode with a sampling rate of 1000 Hz. EDA data in **Study II** were recorded using DC mode at a sampling rate of 1000 Hz. For all three studies, during the recording, the data were filtered with a high cut-off of 250 Hz.

In **Study I**, BrainVision Analyzer 2.1 (Brain Products GmbH, Munich, Germany) was used to preprocess the facial EMG and EEG data. In **Study II**, Ledalab (Version 3.4.9), a toolbox based on MATLAB (R2016b), was utilized to analyze the EDA responses. In **Study III**, MNE Python (Gramfort, 2013; MNE version: 0.21.2; Python: 3.8.6) was utilized to analyze the EEG data.

In **Study I**, the analysis of facial EMG responses from the zygomaticus major muscle and the corrugator supercilii muscle were conducted separately. In accordance with a previous study (Thompson et al., 2016), facial EMG responses were band-pass filtered offline at 20–400 Hz (24 dB/octave), and then a 50 Hz notch filter was applied. Next, the data were segmented from -400 ms to 4000 ms relative to the onset of keywords into epochs and exported to be further processed using a custom MATLAB script (MATLAB, R2015b). With the custom script, epochs with excessively large amplitudes (beyond 250 µV) were removed. After this, each facial EMG epoch was calculated into 11 consecutive 400-ms time windows, and the response from the time window between -400 ms and 0 ms was set as a baseline for each epoch. The facial EMG amplitude percentage relative to the baseline was computed, and the amplitude percentages were then averaged over a time window of 1200 ms into three intervals (Time 1: 0–1200 ms; Time 2: 1200–2400 ms; Time 3: 2400–3600 ms) for each participant and each stimulus condition (non-ironic versus ironic).

In **Study II**, the EDA data for each movie clip and for each participant were first down-sampled to 10 Hz. Data smoothing was then performed, and a continuous decomposition analysis was conducted to extract continuous tonic and phasic activity from the EDA data. Finally, the phasic activity for each participant was averaged for each movie type (emotional dimension).

The preprocessing of EEG data was similar in **Study I** and **III**. In both studies, interpolation for the EEG data was computed to repair the bad channels, and then the EEG data were re-referenced offline to an average over all the channels. In **Study I**, eye movements were detected and corrected according to the Gratton and Coles method (Gratton et al., 1983). After this, the electrode signals were high-pass filtered at 0.1 Hz and low-pass filtered at 20 Hz (24 dB/octave) with a 50 Hz notch filter. EEG data were then segmented into epochs from 100 ms before and 1000 ms after the onset of the keywords. Epochs of all the channels exceeding an amplitude of ± 150 µV at an interval of 200 ms or an amplitude of 75 µV difference between two consecutive time points were removed from further analysis. The mean voltage of the 100 ms prestimulus period was applied as a baseline for each epoch. Finally, the responses for each participant were averaged separately for the congruent (non-ironic) and incongruent (ironic) conditions.

The EEG signals in **Study III**, on the other hand, were filtered with a band-pass filter of 0.1–30 Hz (zero-phase overlap-add Finite Impulse Response filtering). EEG data were extracted into 800-ms epochs starting from 200 ms prior to the onset of the stimulus. The baseline correction was computed for each epoch and channel by subtracting the mean voltage during a period of 200 ms before the onset of the stimulus from every data point of the epoch. Methods for eye movement correction were not applied. Instead, epochs with eye blinks and other artifacts were omitted by following the criterion that epochs containing an amplitude value beyond ± 50 µV were excluded. Finally, for each participant, responses to the deviant (sad faces and happy faces) and the standard immediately preceding the deviants (pre-sad neutral faces and pre-happy neutral faces) stimuli were averaged separately for each mood condition.

In **Study I**, mean amplitude values of N400-like activity and P600 were calculated from the region of interest (ROI) over central electrode sites (N400-like activity) and left and right ROIs over the left and right parietal electrode sites (P600), and from two defined a priori time windows (N400-like activity: 300 to 500 ms; P600: 500 to 800 ms). The time windows were pre-defined based on previous studies (Bornkessel-Schlesewsky & Schlesewsky, 2008; Kutas & Federmeier, 2011), and the electrode pools were selected with a tool based on a data-driven method—cluster-based permutation statistics (Maris & Oostenveld, 2007)—which aimed to limit the number of electrodes for the subsequent analyses investigating group differences (Hämäläinen et al., 2018; Strömmer et al., 2017).

In **Study III**, the mean amplitude values (± 10 ms around the peak) and peak latency of P1, N170, and P2 were investigated. The peak was detected for P1 from a time window of 80–150 ms, for N170 from 130–210 ms, and for P2 from 180–260 ms. The electrode clusters were selected based on previous literature (Astikainen et al., 2013; Batty & Taylor, 2003; Ruohonen et al., 2020) and visual inspection of the grand-averaged data. Electrode channels over the left and right occipital/parieto-occipital sites were applied for P1, N170, and P2.

2.5 Behavioral measures and data analysis

In **Study I**, congruency evaluations and valence ratings of the non-ironic and ironic conversations were collected by participants pressing buttons on a keyboard. For congruency evaluations, the accuracy of congruency detection and response times for each conversation were recorded. For valence ratings, the perceived funniness of each conversation from "very unpleasant" to "very funny" on a scale of -2 to 2 was measured. It is notable that both non-ironic and ironic conversations could be considered as emotional depending on the positive or negative keyword. Detection accuracy was analyzed with a multilevel model, as implemented in Mplus software (Version 8), because the responses produced categorical data. For response times of congruency detection, responses with correct answers of congruency and a duration of less than 2.5 standard deviations from the mean response time were included for further analysis. Finally, the mean values of each participant's response times of congruency detection and valence ratings of conversations were computed separately for non-ironic and ironic conditions.

In **Study II**, the valence of the scene content of each movie clip was measured while participants controlled a joystick (Extreme 3D Pro, Logitech, Europe S.A.) forward or backward. Valence ratings were recorded continuously at a sampling rate of 4 Hz on a scale of -1000 to 1000. For half of the participants, moving the joystick forward represented a positive rating, and backward represented a negative rating, while for the other half of participants, the ratings were reversed. The continuous ratings were analyzed using a custom script in MATLAB (R2016b). The sampling rate of the rating data was reduced to 1 Hz.

Next, the mean valence rating values of each movie clip were calculated for all participants. Because the average valence rating of the movie clip (Amusing 3) was negative based on the calculation, the data in response to the movie clip (Amusing 3) were excluded from further analysis. Intersubject correlation (ISC) for the dynamic valence ratings was calculated as follows. First, for each movie clip, Pearson's correlation coefficients of the time courses of the continuous ratings were computed between one participant and each other participant within the same group (control or depressed group). Next, the individual correlation coefficients were averaged, which gave the ISC value for each movie clip and for each participant. Finally, the ISC values for each participant were obtained by averaging the values for each movie type.

In **Study III**, participants' self-reported mood were measured with the Visual Analog Mood Scale (VAMS) (Luria, 1975). Participants' mood evaluation scores after the resting stage (mood baseline), scores after the mood induction procedure, and scores before the unattended facial expression task were obtained to investigate the efficiency of mood changes.

2.6 Statistical analysis

All statistical analyses described below were carried out using IBM SPSS Statistics (IBM Corporation, NY, USA).

In **Study I**, for behavioral responses, a two-way repeated measure of analysis of variance (ANOVA) was conducted to investigate the effect of Stimulus type (non-ironic versus ironic) within the Group (control versus depressed) separately for response times of congruency detection and valence ratings of perceived funniness. Facial EMG responses in the zygomaticus major muscle and the corrugator supercilious muscle were analyzed separately by performing a three-way repeated measures ANOVA with within-subject variables Stimulus type (non-ironic versus ironic) and Time window (1 versus 2 versus 3), and a between-subject variable Group (control versus depressed). For ERPs, mean amplitude values of N400-like activity were applied in a 2 (Stimulus type: non-ironic versus ironic) × 2 (Group: control versus depressed) repeated measures ANOVA model. P600 responses were analyzed by applying a three-way repeated measures ANOVA, with Stimulus type (non-ironic versus ironic) and ROI (left versus right) as within-subject variables and Group (control versus depressed) as a between-subject variable. Pearson's correlation analysis was conducted separately for non-ironic and ironic conditions between comprehension-related variables (N400-like activity and congruency detection accuracy; P600 response and congruency detection accuracy) and emotion-related variables (facial EMG in the zygomaticus region and valence ratings; facial EMG in the corrugator region and valence ratings). Repeated measures of analysis of covariance (ANCOVA) was conducted to investigate: 1) whether an individual's humor style affected their valence ratings and facial EMG responses (aggressive humor style scores were applied as a covariate); 2) whether cognitive ability influenced P600 responses (three factors extracted from cognitive tests were set as covariates); and 3) whether current antidepressant medication status affected facial EMG responses, ERPs, and behavioral responses in depressed groups (medication status as a covariate). Furthermore, a simple linear regression analysis was conducted to investigate the effect of depressive symptoms on each measure (facial EMG, ERPs, and behavioral responses) for all participants. BDI-II scores were set as a predictor in the analysis.

In **Study II**, the mean phasic EDA values, the mean values of valence ratings, and the valence rating ISC for each movie type and for each participant were measured. Repeated measures ANOVAs with a within-subject factor Movie type (amusing versus sad versus fearful) and a between-subject factor Group (control versus depressed) were performed separately for each measure. The effect of anxiety symptoms (measured by the DASS-Anxiety) and the effect of medication status were explored by conducting repeated measures ANCOVAs in the depressed group, in which DASS-A scores and antidepressant medication status were set separately as covariates. Pearson's correlation coefficients were computed for each movie type within each group between the BDI-II scores and the values of each measure (mean phasic EDA values, mean valence rating values, and valence rating ISC). For the whole sample, Spearman's rank correlation analysis was conducted to investigate the relationship between depressive symptoms and responses in each measure, since the BDI-II scores were not normally distributed.

In **Study III**, VAMS scores were applied in two-tailed paired samples t-tests separately by comparing participants' mood evaluation scores between depressed and neutral moods at three different stages: scores after the resting stage (mood baseline), scores after the mood induction procedure, and scores before the unattended facial expression task. For ERPs, peak latencies in response to neutral standard faces before the sad and happy deviant faces were averaged to reduce the levels for the ANOVA model. Three-way repeated measures ANOVAs were performed separately for peak latencies of P1, N170, and P2, with within-subject factors Mood (depressed mood versus neutral mood), Expression (sad face versus happy face versus neutral face), and Hemisphere (left versus right). For the analysis of the mean amplitudes of P1, N170, and P2, differential responses to sad and happy faces in neutral and depressed moods were calculated by subtracting responses to standard neutral faces from corresponding sad and happy deviant faces, respectively. Differential responses were applied in ANOVA models, with Mood (neutral mood versus depressed mood), Expression (sad-neu versus happy-neu), and Hemisphere (left versus right) as within-subject factors for P1, N170, and P2 separately.

For all three studies, significant interactions observed in ANOVAs were further investigated using independent sample t-tests (between-subject comparisons) or two-tailed paired t-tests (within-subject comparisons). One-sample t-tests comparing differential responses against zero were conducted in **Study III** whenever a significant mood-related effect was found for the differential responses. In **Study I** and **III**, independent t-tests and paired samples t-tests were applied with a bootstrapping method using 1000 permutations (Good, 2005). In **Study II**, Bonferroni corrections were used to adjust the p-values in multiple comparisons. For all three studies, statistics with p-values smaller than 0.05 were regarded as significant. For the ANOVA models in all studies, the Greenhouse-Geisser correction was applied to adjust the p-values whenever the sphericity assumption was violated. The false discovery rate (FDR) (Benjamini & Yekutieli, 2001) was applied to correct the p-values in multiple correlations.

3 RESULTS

In **Study I** and **II**, I investigated how depressive symptoms affect conscious level processing in linguistic (**Study I**) and non-linguistic (**Study II**) stimuli. In **Study III**, I explored the effects of depressed mood on the preattentive processing of facial expressions in healthy participants. For each study, the research questions, hypotheses, and corresponding results are summarized in Table 2.

TABLE 2 Research questions, hypotheses, and corresponding results of each study.

Study	Research questions	Hypotheses	Results
I	Do depressive symptoms affect emotional reactions in response to irony?	• Valence ratings of ironic stimuli are more negative for the depressed group than for the control group. • Differences in facial EMG responses between the ironic and non-ironic stimuli are smaller in the depressed group than in the control group.	• The hypotheses were not supported; valence ratings for both ironic and non-ironic stimuli were more negative in the depressed than in the control group. • The hypotheses were not supported; no group differences were found in facial EMG responses.
	Do depressive symptoms affect cognitive processes of irony comprehension?	• P600 response to ironic stimuli is smaller in the depressed than in the control group.	• The hypotheses were not supported; no group differences were observed in P600 amplitudes. Group difference in P600 to irony was found in hemispheric balance.
II	Are depression-related alternations reflected in the synchronization of emotional movies' dynamic valence ratings?	• Compared to the control group, the depressed participants have lower synchronization in valence ratings to sad movie clips.	• The hypotheses were supported; decreased synchronization of the valence ratings was observed in the depressed group in response to sad movie clips.
III	Does depressed mood affect preattentive change detection of emotional facial expressions in healthy individuals?	• Altered P1, N170, and P2 differential responses in participants undergoing depressed mood are observed.	• The hypotheses were partly supported; the N170 differential responses to deviant faces decreased in depressed mood.

3.1 Study I: Electrical brain activity and facial electromyography responses to irony in depressed and non-depressed participants

In **Study I** I explored the effects of depressive symptoms on the processing of ironic conversations from cognitive and affective aspects: irony comprehension and emotional reactions in response to irony, respectively.

For the behavioral responses, a significant difference between ironic and non-ironic stimuli was observed in the accuracy of congruency detection (p = 0.007). The accuracy of congruency detection was higher for ironic stimuli (M = 97.78%) than for non-ironic stimuli (M = 96.2%). The response times of congruency detection were also analyzed. The main effect of Stimulus type (ironic versus non-ironic) approached significance (p = 0.057). The participants evaluated the congruency of ironic stimuli (M = 2041.99 ms) a bit slower than that of non-ironic stimuli (M = 1992.62 ms). No other main effects or interaction effect were observed in the accuracy and response times of congruency detection.

When comparing the valence ratings of ironic and non-ironic conversations between the depressed and non-depressed participants, the results showed a main effect of Stimulus type (p < 0.001) and a main effect of Group (p = 0.030). Both the depressed and control groups rated ironic conversations (M = 0.27) as funnier than non-ironic conversations (M = -0.11). The control group (M = 0.19) rated all the conversations funnier than the depressed group (M = -0.05). The interaction effect was not significant.

Facial EMG corrugator and zygomaticus activity in response to ironic and non-ironic stimuli were compared between the depressed and control groups. Significant differences between the time windows were observed in corrugator activity (p = 0.009) and zygomaticus activity (p = 0.002). Muscle reactivity in the corrugator region was smaller during the Time window 1 (0-1200 ms, M = 100.4%) than during Time window 2 (1200-2400 ms, M = 101.3%) and 3 (2400-3600 ms, M = 102%). Similar to the reactivity in the corrugator region, responses in the zygomaticus region were also smaller in the time window of 0-1200 ms (M = 101.3%,) than in the time windows of 1200-2400 ms (M = 105.8%) and 2400-3600 ms (M = 105.3%). Regarding the effect of stimulus type, a significant difference was found in the zygomaticus reactivity between ironic and non-ironic conversations (p = 0.039). A larger muscle reactivity was observed in the zygomaticus region in response to ironic stimuli (M = 105.3%) than to non-ironic stimuli (M = 103%) in both groups. There were no other main or interaction effects on facial EMG reactivity.

Concerning ERPs, enlarged N400-like activity (300–500 ms) was found with ironic (M = -0.73 μV) as opposed to non-ironic (M = -0.37 μV) stimuli in both the control and depressed groups (p = 0.007). No other main or interaction effect was observed in the N400-like activity. For P600 (500–800 ms), an interaction effect of Stimulus type, ROI, and Group was found (p = 0.034). Follow-up ANOVAs within each group were conducted, and larger P600 amplitude was also observed with ironic, rather than non-ironic, stimuli in the depressed group ($p < 0.001$; ironic: $M = 1.17$ µV, non-ironic: $M = 0.61$µV) and the control group ($p = 0.026$; ironic: $M = 1.13$ µV, non-ironic: $M = 0.80$ µV). In the depressed group, the interaction effect of Stimulus type and ROI approached significance ($p = 0.065$). The following comparison showed that P600 amplitudes in response to ironic stimuli ($M = 1.44$ µV) were larger than those for non-ironic stimuli ($M = 0.60$ µV) in the right ROI in depressed participants, while in the left ROI, the responses between the stimuli did not differ. No such interaction effect was observed in the controls. Follow-up ANOVAs within each stimulus type were also conducted, and an interaction effect between ROI and Group was observed only ($p = 0.012$) for the ironic stimuli. The post hoc comparison showed that in the depressed group, the P600 amplitudes were more positive in the right ROI ($M = 1.44$ µV) than in the left ROI ($M = 0.90$ µV) for the ironic stimuli ($p = 0.029$), and in the control group, the P600 responses to ironic stimuli in each ROI did not differ.

The correlations between ERPs (the N400-like activity and the P600) and the accuracy of congruency detection were tested separately for ironic and non-ironic stimuli. The correlations between facial EMG (the corrugator and the zygomaticus activity) and valence ratings of the ironic and non-ironic conversations were also examined. The results showed that there was no relationship between the tested conditions.

The main results of valence rating, facial EMG activity, and P600 responses are illustrated in Figure 1.

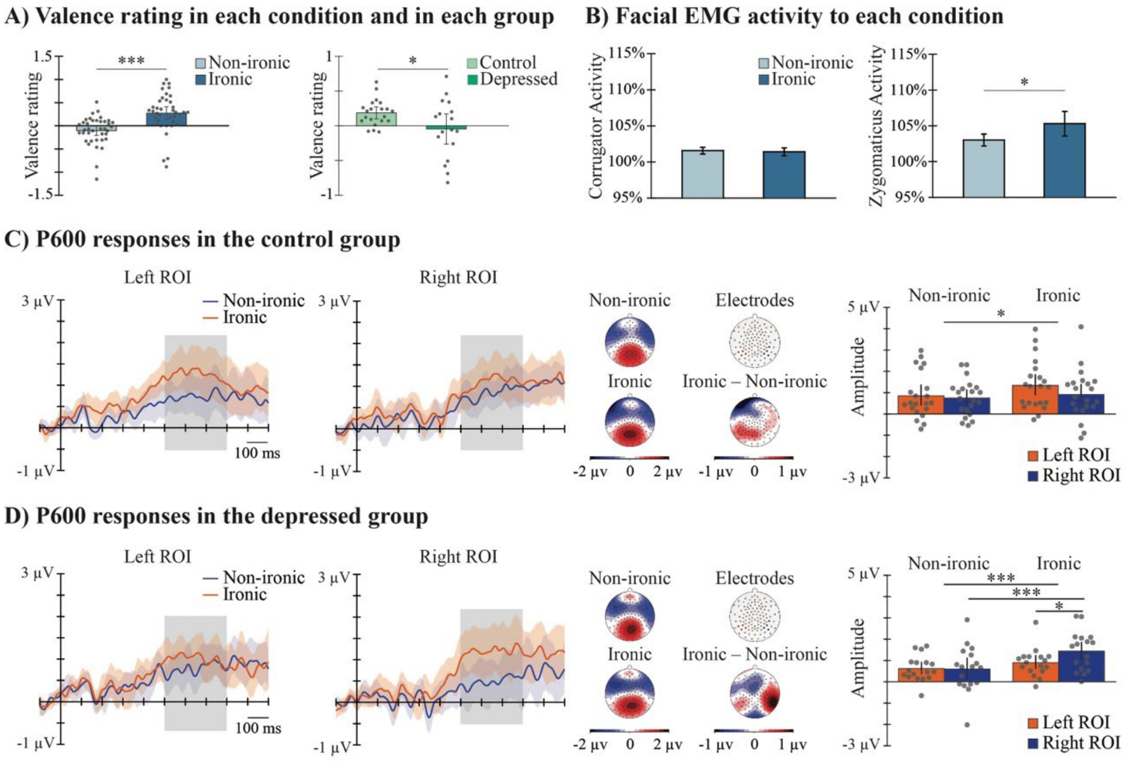

FIGURE 1 Behavioral valence ratings, facial EMG activity, and P600 responses in Study I. A) Valence rating to non-ironic and ironic stimuli (left) and in the control and depressed groups (right). The error bars in the histograms represent 95% confidence intervals. The scatterplot represents individual responses. B) Facial EMG corrugator activity and zygomaticus activity in response to non-ironic and ironic stimuli. The error bars represent standard deviations. C) and D) Grand-averaged waveforms, topographical maps, electrode selections, and mean amplitude values for P600 responses in the control (C) and depressed (D) groups. For the grand-averaged waveforms, the blue and red shadows represent 95% confidence intervals for responses to non-ironic and ironic stimuli, respectively. The gray rectangle shows the time window (300 to 500 ms after stimulus onset) for the analysis of the P600 responses. The red and blue dots represent clusters for the left and right ROI, respectively. The error bars in the histograms represent 95% confidence intervals. Individual participants' P600 amplitudes are presented as scatterplots. Ironic—Non-ironic = a differential response between ironic and non-ironic conditions. For all figures, *p < 0.05; ***p < 0.001. Modified from Li et al. (2020).

3.2 Study II: Decreased intersubject synchrony in dynamic valence ratings of sad movie contents in depressed individuals

In **Study II** I investigated the differences in dynamic valence ratings and EDA for sad, fearful, and amusing movie clips between the depressed and the control participants. Furthermore, I analyzed the intersubject correlations (ISCs) in the dynamic valence ratings of different emotional movie clips across the participants in each group (depressed and control).

For the mean valence rating values for each movie type, a main effect of Movie type was observed ($p < 0.001$). Amusing movie clips ($M = 84.1$) were evaluated as more positive than sad ($p < 0.001$, $M = -272.8$) and fearful movie clips ($p < 0.001$, $M = -306.6$) by both depressed and control participants. There were no other significant main or interaction effects in the mean valence rating values. Furthermore, the participants' anxiety symptoms (DASS-A) did not affect their valence rating values. Correlations between the mean valence rating values and depressive symptoms (BDI-II scores) were examined for each group and for the whole sample. In the depressed group, a negative relationship between the mean valence rating values and depressive symptoms was revealed for the amusing movie clips (r = -0.639, FDR corrected $p = 0.017$). In the control group, and the whole sample there were no correlations between the tested conditions.

For the mean EDA for each movie type, there was a main effect of Movie type ($p = 0.001$). A larger EDA response showing greater emotional arousal to fearful ($M = 0.134$ μS) than to sad ($M = 0.095$ μS) movie clips was found in the whole sample ($p < 0.001$). No other main or interaction effects were found in the mean EDA. Participants' anxiety symptoms (DASS-A) did not affect their EDA for either movie type, and there was no correlation between the mean EDA to each movie type and depressive symptoms (BDI-II scores) for each group or the whole sample.

For the synchronization of the valence rating, an interaction effect of Movie type and Group was observed ($p < 0.001$). The following comparison between the groups for each movie type showed that the ISC in response to sad movies was lower in the depressed ($M = 0.357$) than in the control ($M = 0.542$) group ($p < 0.001$). For amusing and fearful movies, no ISC differences were found between the groups. The ISC of valence ratings for each movie type was also analyzed within each group (depressed and control). For the depressed group, the valence rating ISC was smaller for amusing movie clips ($M = 0.176$) than for sad ($p < 0.001$, $M = 0.357$) and fearful ($p < 0.001$, $M = 0.386$) movie clips. The participants' anxiety symptoms and medication state did not affect the results. In the control group, the valence rating ISC was also smaller for amusing movie clips ($M = 0.201$) than for sad ($p < 0.001$, $M = 0.542$) and fearful ($p < 0.001$, $M = 0.432$) movie clips. Participants showed a larger valence rating ISC to sad than to fearful movie clips ($p < 0.001$). Correlations between the valence rating ISC and depressive symptoms (BDI-II scores) were also investigated for each movie type in each group and the whole sample. The results only showed a negative relationship between the valence rating ISC and BDI-II scores for the whole sample (r = -0.552, FDR corrected $p < 0.005$).

The main results of the mean phasic EDA values and mean valence rating values for amusing, sad, and fearful movie clips are shown in Figure 2. For valence rating ISC, group differences for each movie type and differences of movie type within each group are also illustrated in Figure 2.

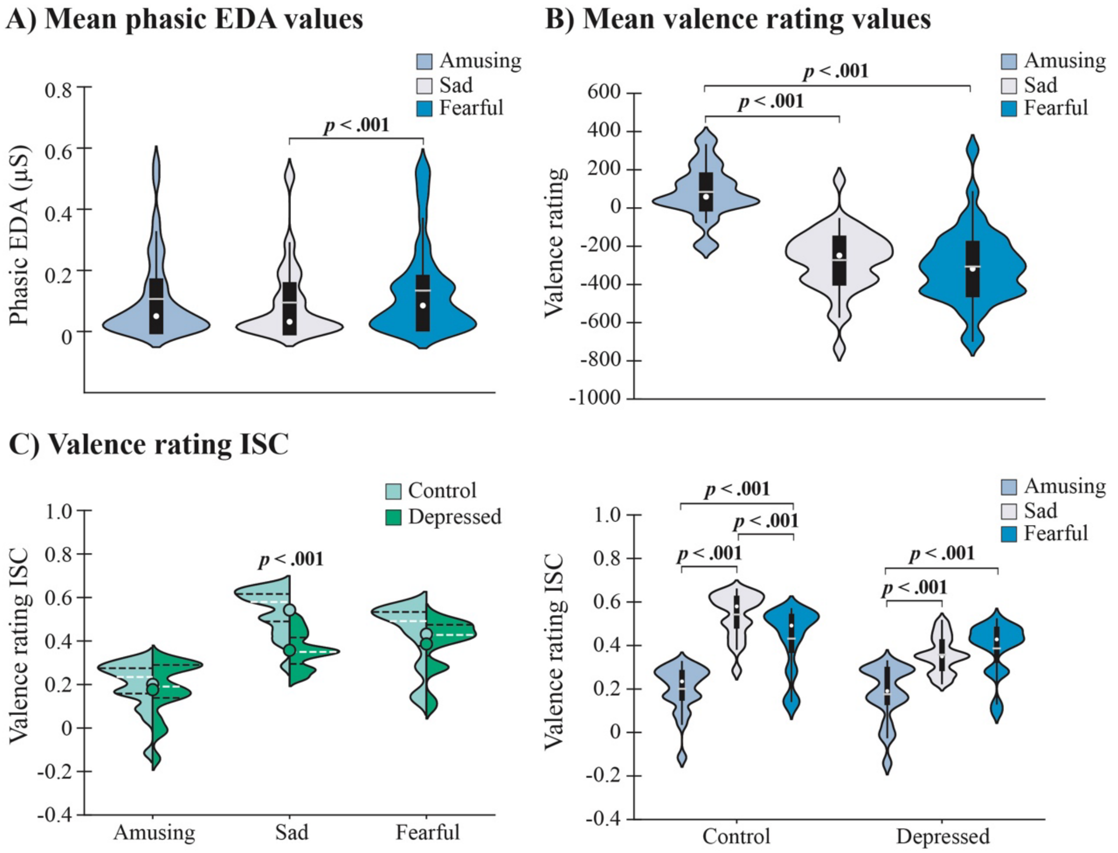

FIGURE 2 Violin plots for mean phasic EDA values, mean valence rating values, and valence rating ISC in Study II. A) Mean phasic EDA values for each movie type averaged over the control and depressed groups. B) Mean valence rating values for each movie type averaged over the control and depressed groups. C) Group differences in valence rating ISC in each movie type (left) and differences in movie type of valence rating ISC within each group (right). For the violin plots showing group differences in valence rating ISC (C. Left), each side of the violin plot corresponds to a different group. Color dots represent the means of the valence rating ISC for the corresponding group. Horizontal white dash lines indicate the median of the valence rating ISC and black dash lines show the interquartile range (IQR) of the valence rating ISC in each group. For the other violin plots, the white dots represent the median of the EDA, the mean valence rating values, and the valence rating ISC. The horizontal gray lines on the violin plots show the mean of the EDA, the mean valence rating values, and the valence rating ISC. The black bars in the center of the violin plots indicate the IQR of the EDA, the mean valence rating values, and the valence rating ISC. The black lines stretched from the bars show the lower and upper adjacent values (1.5 times the IQR) of the EDA, the mean valence rating values, and the valence rating ISC. Modified from Li et al. (2021).

3.3 Study III: Effect of depressed mood on preattentive change detection of facial expressions

In **Study III**, I investigated how an induced depressed mood, compared to a neutral mood, affected the change detection of emotional facial expressions in healthy participants.

VAMS scores were applied to measure participants' mood during the measurement. The VAMS scores after the resting stage (baseline), after the mood induction procedure, and before the unattended facial expression task were compared separately between the neutral mood and depressed mood conditions. The results showed that after the mood induction procedure participants rated their mood as more negative on depressed (M = 2.99) mood day than on neutral (M = 5.20 cm) mood day ($p < 0.001$). Before the unattended facial expression task, the mood state stayed as that after the mood induction procedure: the VAMS scores were more negative for the depressed (M = 2.69 cm) mood condition than for the neutral (M = 5.01 cm) mood condition ($p < 0.001$). The mood after the resting stage did not differ between the two measurement days.

For ERP amplitudes, the differential responses (sad deviant minus corresponding neutral standard; happy deviant minus corresponding neutral standard) of P1, N170, and P2 were investigated. For the P1 differential response, an interaction effect between Mood and Expression was observed (p = 0.017). Further analysis showed that the P1 differential response to deviant happy faces was negative (M = -0.48 μV), and the response to deviant sad faces was in a positive polarity (M = 0.31μV) when participants were experiencing a neutral mood ($p < 0.001$). In a depressed mood, no such differences were found for deviant happy and sad faces. The other main or interaction effects were not found for the P1 differential response. For the N170 differential response, there was a main effect of Mood (p = 0.042) and a main effect of Hemisphere (p = 0.048). The N170 differential response to deviant faces was more negative when participants were in a neutral mood (M = -0.72 μV) than in a depressed mood (M = -0.43 μV). The N170 differential response to deviant faces in the right hemisphere (M = -0.77 μV) was larger than the response in the left hemisphere (M = -0.36 μV). No other main or interaction effects were observed for the N170 differential responses. For the P2 differential responses, there was no mood effect, facial expression effect, or interaction effect between the two variables. For the peak latencies of P1, N170, and P2 responses to sad, happy, and neutral faces, the ANOVAS with within-subject factors Mood (depressed mood versus neutral mood), Expression (sad face versus happy face versus neutral face) and Hemisphere (left versus right) showed that no main or interaction effects were found.

Grand-averaged waveforms, electrode selections, topographical maps, and mean amplitudes of differential responses for P1 and N170 are illustrated in Figure 3.

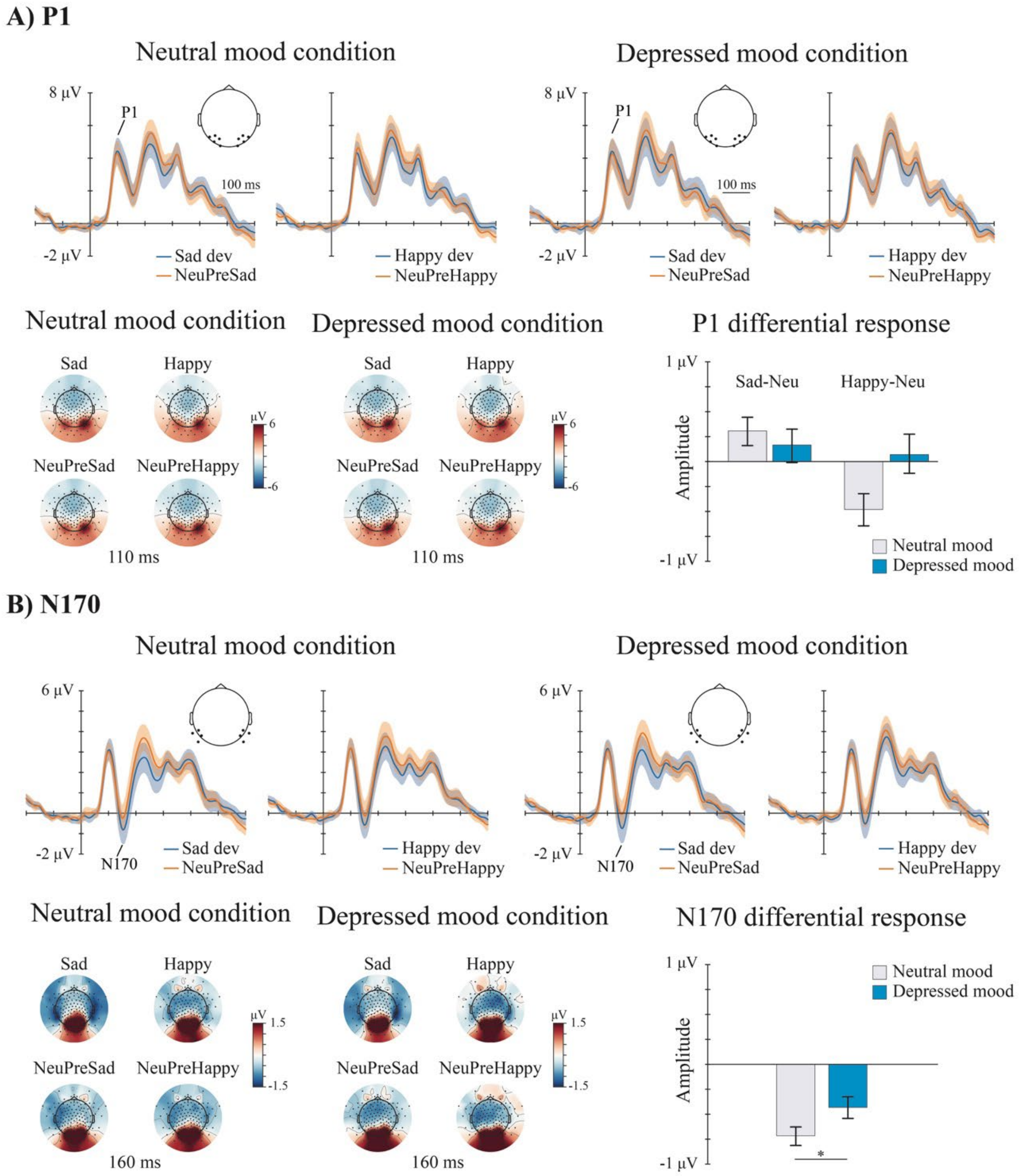

FIGURE 3 P1 and N170 responses in depressed and neutral mood conditions in Study III. A) Grand-averaged waveforms, electrode selections, topographical maps, and mean amplitudes of differential responses for P1. B) Grand-averaged waveforms, electrode selections, topographical maps, and mean amplitudes of differential responses averaged over facial expression for N170. The mean amplitude values of P1 and N170 were calculated from the selected electrodes and the responses of ±10 ms around the peaks. For the grand-averaged waveforms, the blue and red shadows represent 95% confidence intervals for the corresponding responses. The error bars in the histograms represent the standard error. Sad dev = sad deviant face; Happy dev = happy deviant face; NeuPreSad = neutral face preceding sad face; NeuPreHappy = neutral face preceding happy face; Sad-Neu= sad deviant minus pre-sad neutral standard; Happy-Neu= happy deviant minus pre-happy neutral standard; *$p < 0.05$.

4 DISCUSSION

The aim of this dissertation is to investigate the effects of depressive symptoms and depressed mood on the processing of emotional information. The effects of depressive symptoms were examined by comparing responses between non-depressed and depressed individuals (those who have an elevated number of depressive symptoms), while the effects of depressed mood were explored in healthy participants with induced depressed mood. The processing of emotional information explored in this dissertation mainly includes the processing of ironic conversations (**Study I**), responses to emotional movies (**Study II**), and preattentive change detection of emotional facial expressions (**Study III**).

Study I looked at irony comprehension and irony-related emotional reactions in healthy and depressed participants. Behavioral responses, facial electromyography (EMG) in corrugator and zygomaticus muscle areas, and event-related potentials (ERPs) were measured. More positive valence ratings and larger facial EMG responses in the zygomaticus major indicating smiling were observed in response to ironic rather than non-ironic stimuli in both the depressed and control groups. However, the valence ratings for all the ironic and non-ironic stimuli were generally more negative in the depressed group than in the control group. Concerning brain responses, enlarged N400-like activity and P600 in response to ironic rather than non-ironic stimuli were found in both the control and depressed groups. Group difference was found in P600: The P600 modulation to ironic stimuli was right-dominant in the depressed group and equal in amplitude in both hemispheres in the control group.

Study II investigated the differences in dynamic valence ratings and electrodermal activity (EDA) for sad, fearful, and amusing movie clips between depressed and control participants. Importantly, synchronization across the participants in each group (depressed and control) in the valence ratings in response to different emotional movie clips was studied. The synchronization of dynamic valence ratings was analyzed using intersubject correlation (ISC), which reflected the variability of the participants' continuous rating of the movie content. For the mean valence rating values and mean EDA for each movie type (sad, fearful, amusing), no group differences were observed. Amusing movie clips were evaluated by all samples as more positive than sad and fearful movie clips. A larger EDA response showing higher emotional arousal to fearful than to sad movie clips was found in both groups. For the synchronization of valence ratings, decreased ISC in the depressed group was observed in response to sad movies compared to the control group.

Study III aimed to explore how induced depressed mood, compared to neutral mood, affect the preattentive change detection of emotional facial expressions in healthy participants. When comparing participants' moods between the two measurement days, there was no difference in Visual Analog Mood Scale (VAMS) scores before the mood induction procedure (baseline), while the VAMS scores were more negative before the unattended facial expression task on the depressed mood day than on the neutral mood day. Concerning the differential responses of ERPs (sad deviant minus corresponding neutral standard; happy deviant minus corresponding neutral standard), the results showed that the amplitude of the N170 differential response was larger in response to the deviant emotional faces when the participants were in neutral mood than in depressed mood. On the other hand, unexpected results related to the P1 differential responses were observed: the P1 amplitude was larger for neutral standard faces than for happy deviant faces when participants were experiencing a neutral mood. For P2 differential responses, mood effect, facial expression effect, or interaction effect between the two variables were not observed. There were no such effects in any of the peak latencies of each ERP component either.

4.1 Cognitive processing of and affective reactions to irony conversations in depression

In **Study I,** the results of behavioral responses suggested that participants' detection accuracy for congruence was greater for ironic stimuli than for non-ironic stimuli in the depressed and control groups. The response time for congruence detection was marginally longer for incongruent stimuli (irony) than for congruent stimuli (non-irony), but not statistically significant. The greater effort required to interpret the ironic cues might explain the longer reaction time. The accuracy and response time of congruence detection did not differ between the two groups, which is in line with earlier investigations showing that depressed individuals do not necessarily have difficulty detecting semantic violations (Deldin et al., 2006; Klumpp et al., 2010).

For valence ratings of the conversations, both groups found ironic stimuli funnier than non-ironic stimuli. This finding is in line with previous irony-related studies in healthy participants, in which ratings of ironic and literal sentences (Calmus & Caillies, 2014; Dews et al., 2009) and ratings of degree of humor in ironic and literal stories (Akimoto et al., 2014) were investigated in non-depressed participants. Here, a group difference was observed in the valence ratings of the conversations. The depressed group had lower valence ratings than the control group for all stimuli (non-ironic and ironic), which is consistent with previous studies suggesting that depressed participants are less responsive to emotional stimuli, such as emotional pictures and films (Bylsma et al., 2008; Moran et al., 2012; Rottenberg et al., 2005). Here, the disparity in the valence ratings of the two groups may not be related to participants' humor style preferences because our data showed that there was no significant difference in any of the assessed humor styles between the groups (see the supplementary materials of **Study I**).

Corresponding to the valence ratings, the zygomaticus muscle activity that implies smiling (Boxtel, 2010) exhibited a greater reaction to ironic stimuli than to non-ironic stimuli in both groups. This finding suggests that ironic stimuli elicited positive emotions in both groups. Similar results were found in a previous study employing facial EMG to investigate irony-related emotional reactions, in which enhanced smiling was observed in response to ironic criticism (Thompson et al., 2016). When comparing the group differences, the depressed and control groups had identical facial EMG responses. This result was unexpected, given the well-known depression-related alterations when processing emotional information (Gotlib & Joormann, 2010; Leppänen, 2006) and the decreased inclination to react to amusing stimuli (Falkenberg et al., 2011; Uekermann et al., 2008). One reason that could explain the identical facial EMG responses in the two groups is related to the stimuli. That is, there is only a small disparity in valence ratings between ironic and non-ironic stimuli. Therefore, similar to the depressed group, the control group rated ironic stimuli only a little more amusing than the non-ironic conversations overall. The significant variance in the depressed group's valence ratings and the zygomaticus facial EMG might also account for the absence of group differences. The variability among depressed individuals might be associated with participants' differences in symptom profiles and the number of symptoms, and the different diagnoses the participants had.

Regarding the ERP data, modulation of both N400-like activity and P600 associated with irony were observed. The enlarged ERP modulations in response to ironic rather than non-ironic stimuli showed evidence to support the two-stage model of ironic processing (Giora, 2003; Grice, 1975) rather than the view that irony could be directly accessed as literal statements (Gibbs, 2002). Furthermore, the elicitation of N400-like activity followed by P600 suggested that the processes of the ironic stimuli in **Study I** were in line with the traditional standard pragmatic view (Grice, 1975). That is, participants may encounter conflicts between a punchline and a literal context (N400-like activity), and then integrate the information to interpret the implied ironic meaning (P600).

The polarity of the N400-like activity was more negative for ironic stimuli than non-ironic stimuli. Compared to the traditional N400 (Kutas & Federmeier, 2011), the N400-like activity in **Study I** did not have a clear peak in morphology and was slightly frontally distributed in topography. This was probably affected by the design of the stimuli. In **Study I**, the position of the keywords varied in the spoken sentences, while in many previous studies, the keywords were usually allocated to the same position, such as at the end of the sentence (Filik et al., 2014; Regel et al., 2011, 2014). In addition to irony-related studies (Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014), previous studies in nonliteral language, such as humor (Coulson & Wu, 2005; Coulson & Kutas, 2001) and metaphor (Coulson & Van Petten, 2002), have also found larger N400 amplitudes for nonliteral than for literal stimuli. Accordingly, the enhanced N400-like activity in response to ironic stimuli may indicate that the participants had difficulties processing the commenting statement in light of the contrasting contextual pictures. Some researchers have not found N400 modulation for ironic stimuli (Balconi & Amenta, 2008; Regel et al., 2011, 2014). According to Regel et al. (2011, 2014), the absence of N400 modulation for ironic stimuli suggests that participants could perceive ironic meaning solely by relying on the given context without any semantic interpretation difficulties. In **Study I**, although the participants did not report difficulties in semantic interpretation of ironic conversations, all the participants had high accuracy in behavioral responses of congruence detection, while the N400 amplitude was still larger for the ironic stimuli than for the non-ironic stimuli. The findings of the N400 modulation to ironic stimuli should be evaluated cautiously, since the morphology and topography of the response was atypical for the traditional N400.

The depressed and control groups showed no differences in N400-like activity in response to ironic stimuli. The results support prior findings that individuals with mood disorders exhibit normal semantic processing when they passively view congruent and incongruent sentences, as they show no differences in N400 amplitude in response to the sentences compared to the controls (Deldin et al., 2006).

As expected, the amplitude of the P600 was larger in positive polarity for the ironic statement than for the non-ironic statement. This finding is in line with previous studies on irony comprehension (Baptista et al., 2017; Caillies et al., 2019; Filik et al., 2014; Regel et al., 2011, 2014). In **Study I**, EEG-electrode sites for the analysis were selected based on a data-driven method, and two regions of interest (ROIs) located in the left parietal and right parietal electrode sites were observed for the P600 modulation. This method was different from previous studies in which ROIs were selected in accordance with previous literature (Caillies et al., 2019) or set as fixed in several brain regions (Filik et al., 2014; Regel et al., 2011, 2014). Even though the electrode sites were selected based on a different method from previous studies, the non-depressed participants in **Study I** showed irony-related P600 modulation mainly in the central and parietal electrode sites, which is consistent with previous irony studies in healthy individuals (Filik et al., 2014; Regel et al., 2011). Furthermore, as in previous studies (Filik et al., 2014; Regel et al., 2011, 2014), no differences were found between the left and right parietal electrode sites in the non-depressed participants in **Study I**. Here, the larger amplitude of P600 in relation to irony is unlikely to be associated with the demands of the comprehension or categorization tasks (Regel et al., 2011; Filik et al., 2014), as the participants listened to the conversation and viewed the pictures without any tasks during the psychophysiological data recording. On the other hand, the enhanced P600 in response to ironic stimuli may not reflect the emotional processing of irony, as suggested by Regel et al. (2011), because no significant relationship between the amplitude of P600 and the behavioral valence ratings of the ironic conversations were observed. Therefore, the enhanced P600 in response to ironic conversation probably represents the demand for increasing inferential efforts to resolve conflicts between ironic punchlines and contextual pictures.

Group difference was observed in P600 in **Study I**: depressed participants showed enhanced P600 response to ironic stimuli on the right ROI compared to the left ROI, while irony modulation in the non-depressed participants did not differ between the two ROIs. One previous study (Kalatzis et al., 2004) classified depressed and control participants based on P600 responses using a machine learning method. The results showed that the accuracy was higher when applying P600 responses from the right electrode site than when applying responses from the left site. As suggested by Kalatzis et al. (2004), the different accuracies could be linked to the dysfunction of the right hemisphere in depression (e.g., hyperactive right hemisphere in depression) (Atchley et al., 2003; Hecht, 2010). Further studies are needed to investigate the underlying causes of the hemispheric difference in P600 amplitude in depression and its functional significance.

4.2 Dynamic ratings of emotional movies' valence in depression

In **Study II**, the results showed that the synchrony of behavioral valence ratings of movies, indexed by the ISCs across the participants, was lower in the depressed group than in the healthy control group. Importantly, the lower synchrony of valence rating in the depressed group compared to the control group was specifically for sad movie clips. Similar results have been found in previous neuroimaging studies in which lower synchrony of fMRI responses to dynamic stimuli in autism (Byrge et al., 2015; Hasson et al., 2009; Salmi et al., 2013), schizophrenia (Tu et al., 2019; Yang et al., 2020), and melancholic MDD (Guo et al., 2015) were observed compared to neurotypical controls. It seems that neurodevelopmental and psychiatric disorders have increased variability across individuals in response to dynamic stimuli at the brain level, and **Study II** extends this finding to behavioral responses.

Concerning the increased variability in the valence rating of movies in depressed participants in **Study II**, one possible explanation was suggested by an earlier study investigating the synchrony of fMRI responses to movies in depressed groups (Guo et al., 2015). In this study, the authors found that depressed participants, compared to the controls, had lower synchrony of fMRI responses. The authors suggested that the reduced synchrony in depression might reflect the altered neural processes elicited by negative movie content: depressed participants were likely to respond to the negative stimuli based on their individual experiences, which are disparate, as they had different depressive symptoms and causes of depression. Alternatively, in **Study II** the valence ratings in the control group could be related more to the stimulus-dependent reaction elicited by the movies, and hence their ratings were more consistent. In contrast, in the depressed group, when rating the movies, the depressed participants were more likely to face interference from their inner processes, and hence they experienced more personal thoughts and feelings than the non-depressed controls during rating. In addition, depressed participants may intend to make more effort in emotion regulation and engage in rumination (Berman et al., 2011; Koster et al., 2011). One earlier study from our laboratory (Hautala et al., 2016) using an eye-tracking method found that when viewing a video about emotional and neutral conversations between two people, the more depressive symptoms the participants had, the less synchronized the participants' gazing followed the conversation flow. This result indicates that depressed individuals have difficulty following the flow of social interactions. In **Study II**, there were also scenes related to social interactions in the movie clips, although it is uncertain whether the higher synchronization of dynamic valence ratings is related to the contents of social interactions.

The findings of **Study II** indicated a depression-related effect in the synchrony of valence ratings of mood-congruent stimuli, as less synchronization of dynamic ratings in the depressed group than in the control group was found specifically in response to sad movies. In addition, for all the participants, more depressive symptoms resulted in less synchrony in the ratings of sad movies across participants. The results supported our hypothesis. That is, because of the mood-congruent processing bias in individuals with depression (Beck, 1967, 2008), it can be assumed that negative emotional content, especially sad content, could have activated automatic, subjective, and individually varying negative thoughts and memories, which led to larger variability in responses within the depressed group than in the control group. Furthermore, this result in **Study II** is also consistent with a previous neuroimaging study (Guo et al., 2015) in which depressed participants showed reduced synchrony in their fMRI responses to movies with negative emotions in comparison with controls. However, in this previous study (Guo et al., 2015), movies were not divided into specific emotional categories, such as the stimuli in **Study II** (sad, fearful, and amusing). Therefore, the authors did not investigate whether the decreased synchronization in depression was specific to sad content or, in general, to negative content (Guo et al., 2015). The results of **Study II** suggest that decreased synchrony in depression might be specific to sad content, but more studies on neural and behavioral responsiveness are needed to confirm this.

There were no group differences in the ISC of valence ratings for fearful and amusing movies. For the fearful movies, the similar ISCs observed in both groups are in line with expectations, as it is not common to observe negative attentive bias to fearful stimuli in depression, whereas it is a typical finding in anxiety (Armstrong & Olatunji, 2012; Peckham et al., 2010). Regarding amusing movies, previous studies have reported that depressed participants exhibit less positive subjective feelings and a lower frequency of facial expressions in reaction to pleasant stimuli than non-depressed individuals (Dunn et al., 2004; Rottenberg et al., 2002; Sloan et al., 1997, 2001), and depressed people also show lower emotional reactivity to emotional stimuli in general (Bylsma et al., 2008; Moran et al., 2012; Rottenberg et al., 2005). However, the ISCs, as well as the mean values of dynamic ratings, in response to amusing movies did not differ between the depressed and control groups in **Study II**. One possible reason could be that in **Study II**, participants evaluated the valence of the content of movie clips rather than their emotional experiences in reaction to the movies, which is different from previous studies (Dunn et al., 2004; Rottenberg et al., 2002; Sloan et al., 1997, 2001).

Previous studies have shown that highly arousing stimuli cause attentional capture and make individuals focus on similar emotional features (Vuilleumier, 2005; Yiend, 2010). Accordingly, brain activities are synchronized between people, as reflected by enhanced ISC in sensory and attention networks based on participants' fMRI responses (Nummenmaa et al., 2012). It is possible that in **Study II** the differences between depressed and control groups in the synchronization of dynamic ratings of sad movies is due to their different arousal levels in reaction to the movies. However, the arousal level of the movies did not explain the results of valence rating ISC, since the amplitude of EDA, indicating participants' arousal for the movies, did not differ between the two groups.

In **Study II**, the lowest ISC of dynamic valence ratings were found for amusing movie clips in both the depressed and control groups. This could be associated with an attention-related phenomenon. That is, previous studies have found that negative emotions force individuals to be more engaged to the stimuli to increase the probability of survival, whereas positive emotions encourage people to pay attention to various external information and engage in play and exploration (Bishop, 2007; Fredrickson, 2001; Fredrickson & Branigan, 2005; Johnson et al., 2010). It is possible that participants had spatially broader attention to amusing movies than to movies with negative valences (sad and fearful), which led to a lower valence rating ISC for amusing than sad and fearful movies. However, since we did not directly measure participants' attention to movies, for example with an eye tracking method, further studies are required to confirm the relationship between attention and ISC.

4.3 Preattentive change detection of emotional facial expressions in healthy participants in depressed mood

In **Study III**, the mood effect was observed for the N170, as evidenced by the decreased amplitude of the N170 differential response (deviant–standard) to faces during depressed mood. The N170 is a visual ERP that has been reported to be related to the automatic encoding of the structure of the face (Batty & Taylor, 2003; Bentin et al., 1996; Hinojosa et al., 2015). Therefore, the results suggest that participants' preattentive change detection of emotional faces, especially the structural encoding phase, is disrupted by depressed mood. This finding is partly supported by a previous study that investigated mood effects on preattentive change detection in the auditory modality (Pinheiro et al., 2017). Pinheiro et al. (2017) found reduced MMN amplitude in response to deviant sounds when participants were primed to a negative mood, indicating that participants' change detection of unattended sounds was impaired when they were in a negative mood. A decreased amplitude of N170 differential responses to deviant faces was also observed in a depression-related study (Chang et al., 2010). In this study, depressed and non-depressed participants and non-depressed controls viewed schematic emotional faces in a passive oddball paradigm. The results showed that, compared to the control participants, depressed participants had decreased amplitudes of N170 and P250 differential responses (reflecting early and late vMMN, respectively) to emotionally deviant faces. The authors suggested impairment in the preattentive change detection of facial expressions in depression (Chang et al., 2010). Taken together, the induced depressed mood in healthy individuals may have a similar effect on N170 to that of depression. This finding is logical since one of the primary symptoms of depression is a sustained depressed mood (WHO, 2010). However, the conclusion should be made with caution because other studies investigating the preattentive change detection of facial expressions in depression have not observed such results (reduced N170 amplitudes) in depressed participants (Ruohonen et al., 2020; Wu et al., 2017; Xu et al., 2018). More studies are required to confirm whether healthy participants in depressed mood have similar amplitude decreases in N170 in response to deviant faces, as do those with clinical depression.

The mood effect was not pronounced for P1 and P2. Regarding P1, an unexpected result was found, showing that in a neutral mood, P1 amplitude was larger for neutral standard faces than for happy deviant faces. In previous studies on the change detection of facial expressions, the ERP amplitudes have usually been larger in response to deviant than standard stimuli (Astikainen & Hietanen, 2009; Kimura et al., 2012; Stefanics et al., 2012; Susac et al., 2004; Zhao & Li, 2006). Thus, in **Study III** the larger P1 amplitude to neutral standard faces than happy deviant faces cannot be interpreted as evidence of deviance detection. Furthermore, previous studies also investigated automatic deviance detection of facial expressions and compared P1 amplitudes between neutral standard faces and emotionally deviant faces (fearful and happy faces in Astikainen and Hietanen (2009); happy and sad faces in Ruohonen et al. (2020)), between happy standard and deviant faces (Stefanics et al., 2012), and between happy standard and neutral deviant faces (Susac et al., 2004). For these comparisons, none of the studies observed any differences in P1 between stimulus types in the healthy individuals. On the other hand, a negative bias toward sad faces, as reflected by larger differential P1 responses to sad faces, was not observed in healthy participants who were in induced depressed mood. However, in depressed participants, larger P1 amplitudes of sad facial expressions than neutral expressions were observed in the early automatic processing of faces (Dai & Feng, 2012; Ruohonen et al., 2020; Zhang et al., 2016). In addition, the amplitude of P1 differential responses to sad deviant faces decreased when the participants' depressive symptoms decreased (Ruohonen et al., 2020). Taken together, it seems that P1 amplitude in preattentive change detection of faces may have the potential to be used as a biomarker for depression diagnosis, as the induced depressed mood does not similarly affect P1 as has been noted in previously reported findings about depression (Ruohonen et al., 2020). However, further studies are needed to confirm these findings in depressed participants and participants with induced depressed mood.

Concerning P2, no mood effect was observed for deviant happy and sad faces. One previous study (Chen et al., 2008) presented positive and negative pictures to participants and compared their ERP responses when they were in sad and happy moods. The researchers found that participants had increased differences in P2 amplitudes between the positive and negative pictures when they were in a sad mood, indicating a mood effect on P2 amplitudes. However, in this study (Chen et al., 2008), the participants were instructed to attend to the stimuli and categorize the valence of the pictures. Also, the music for mood induction was presented in the same experimental block, which means participants needed to change their mood frequently during the recording. Our study was methodologically different because in **Study III**, participants passively viewed the faces (unattended) without any tasks, and the mood induction procedure for depressed and neutral moods was given on two separate days. Further studies are needed to better understand the effects of attention, task, and mood induction procedures on P2 and the modulations of the other ERPs.

In **Study III**, mood effects on ERP latencies (peak latencies of P1, N170, and P2) were also tested. The results showed that there were no significant differences in ERP latencies between depressed and neutral moods. This finding stands alone since it has not been previously investigated whether mood modulates ERP latencies in relation to preattentive change detection. On the other hand, the ERP latencies to sad, happy, and neutral faces did not differ in **Study III.** This result is consistent with previous studies (Astikainen et al., 2013; Kreegipuu et al., 2013; Ruohonen et al., 2020), indicating that facial emotions are unlikely to affect ERP latencies in preattentive change detection.

Based on the results from **Study III**, the mood-congruent effect on the ERPs related to the deviance detection of unattended facial expressions was not observed. Previous studies have reported mood-congruent effects when applying other experimental paradigms (e.g., attended recognition tasks) (Bouhuys et al., 1995; Chepenik et al., 2007) or in depressed groups (e.g., attended negative bias to sad faces) (Dai & Feng, 2012; X. Wu et al., 2016; Zhang et al., 2016; Zhao et al., 2015). These experimental designs are different from those in **Study III**, as participants in **Study III** were instructed to attend to a calculation task instead of focusing on facial stimuli. It could be further investigated whether the mood-congruent effect is more pronounced in attentive face processing.

4.4 Limitations

This dissertation has several limitations. First, some limitations were related to the selection of participants. In **Study I** and **II**, depressed participants were recruited based on their BDI-II scores, and not all of them had a recent diagnosis of depression. Although BDI-II is commonly applied to measure people's depressive symptoms, and all the depressed participants in **Study I** and **II** had current scores of no less than 13, which can at least be considered mild depression (Beck et al., 1996), the results of **Study I** and **II** could not necessarily be applied to clinical depression. In addition, there were 10 depressed participants in **Study I** (n = 17) and 9 depressed participants in **Study II** (n = 21) taking antidepressant medication at the time of the study. However, analyses with the current medication status as a covariate suggested that medication did not significantly affect the results in **Study I** and **II**. In **Study I**, most of the participants were females in both the depressed and control groups. Thus, it could not be confirmed that the findings would well generalize to all genders. Nevertheless, the gender distribution was comparable in the depressed and control groups in **Study I**.

Second, there were limitations related to the experimental stimuli. In **Study I**, half of the ironic conversations were ironic praise, and the other half were ironic criticism. Because there were a limited number of trials for each sub-type of stimuli, it was not possible to investigate the effects of ironic praise and ironic criticism separately. It is plausible that if only ironic criticism was utilized in **Study I**, participants, at least the healthy control participants, would have more positive valence ratings for ironic conversations (Dews et al., 2009; Thompson et al., 2016), which may also increase group differences in facial EMG reactivity. In **Study II**, all the movie clips were silent, and the captions were not displayed, which might have reduced the participants' emotions in reaction to the movies. However, this setting could also to some extent avoid linguistic-related confounding, and spatial distractions of captions, which was the main reason why silent movies without captions were opted. On the other hand, as the movies were muted in **Study II**, it might have been more difficult to understand the conversations in the movies. To minimize this effect, there was a brief description of the storyline presented before each movie clip. In addition, in **Study II**, participants only rated movies' valence as negative or positive but did not categorize the movie clips into each movie type (amusing, sad, and fearful). However, all the movies were selected and categorized based on the previous results of the ratings of subjective feelings (Schaefer et al., 2010). In **Study III**, because emotional faces were rarely presented, while neutral faces were standard stimuli that were frequently presented, it was not possible to isolate the effects of face rarity and emotionality on ERPs. Previous studies that compared ERP responses to rare and frequent emotional faces in a passive oddball paradigm found larger N170 amplitudes in response to emotionally deviant faces in comparison to the same face as a standard (fearful and happy faces: Stefanics et al. (2012); sad and happy faces: Xu et al. (2018)). Therefore, it can be assumed that the N170 modulation in **Study III** is probably associated with the rareness of deviant faces.

Third, there were limitations in relation to the design of the experiment and the analysis models as well. In **Study I**, we did not directly measure participants' comprehension of the ironic and non-ironic conversations. Future studies may consider adding questions related to the semantic interpretation of the stimuli, which could provide evidence that participants comprehend the implied ironic meanings. In **Study II**, the inter-subject correlation of the valence ratings was calculated across the time-points for each movie clip, which showed how the ratings varied across the participants. It would also be interesting to investigate the dynamic valence rating by applying time-series analyses, which could provide information on how the valence rating develops as the movie clip unfold in the two groups.

4.5 General discussion and future directions

This dissertation investigated alterations related to depression symptoms in cognitive and affective aspects of irony processing, the synchrony across participants in conscious valence ratings to emotional movies, and effects of depressed mood on preattentive facial expression processing in healthy people. **Study I** showed alterations in cognitive processing to ironic conversations in depressed participants, as evidenced by the hemispheric imbalance of P600 modulation to ironic stimuli. More negative valence ratings to all the stimuli were also found in the depressed group, indicating reduced responsiveness during emotional information processing. **Study II** observed lower synchronizations of valence ratings to sad movie contents in the depressed participants than in the controls, suggesting that depression-related negative bias could increase individual variability in emotional information processing. **Study III** found that depressed mood disturbed healthy participants' structural encoding of faces, as reflected by the N170 amplitude of deviant faces.

One strength of the dissertation is the novel methodology applied in **Study I** and **II**.

The first highlight of the methodology is the design of the stimuli. To be specific, in **Study I** ironic conversations are more natural and less predictable compared to previous irony-related ERP studies where ironic punchlines were always in a fixed position (Filik et al., 2014; Regel et al., 2011, 2014). This is because the stimuli in **Study I** were spoken dyadic dialogues resembling conversations in people's daily lives, and the punchlines were allocated to different positions in the commenting sentences. Importantly, in **Study I**, the preceding contextual pictures determined the conversation to be ironic or non-ironic, and the commenting sentences that included the punchlines were physically similar. This setting avoids confounding related to the low-level stimulus features and punchline positions, and thus allows a valid comparison between the ironic and non-ironic conditions. Concerning **Study II,** emotional movie clips were applied as dynamic stimuli, containing rich information, and could better represent our real-life environment than, for example, static pictures.

The second advantage of the methodology is the analysis of dynamic valence ratings in **Study II**, which explored participants' synchronization in dynamic ratings of emotional movies, and the ISCs of valence ratings across participants within each group (depressed and controls) were calculated and compared. The ISC examines the stimulus-related variances across the participants and reflects the correlations of dynamic valence ratings across individuals when they are viewing and evaluating the same movie content. Applying ISC analyses in **Study II** complements previous brain studies (Guo et al., 2015) and is the first to demonstrate desynchronization in the behavioral valence rating of movies in depression.

There are also other advantages to the methodology of the dissertation. For instance, **Study I** and **II** applied multimodal measures to investigate automatic psychophysiological reactivity from the brain and the body, and conscious behavioral responses in emotional information processing, which could provide a comprehensive understanding of the phenomenon under investigation. Additionally, in **Study I** and **II**, the behavioral responses were recorded on a separate day after the recordings of psychophysiological reactivities (**Study I**: EEG and facial EMG; **Study II**: EEG and EDA). This setting allowed participants to listen naturally to or view the stimuli without any explicit tasks during the psychophysiological measurements. On the other hand, the behavioral ratings are most probably valid, even if the same stimuli were presented for the second time, since repeated exposure to stimuli did not have any significant effect on valence ratings of stimuli contents in a previous study (Itkes et al., 2017).

Concerning the findings of the doctoral dissertation, **Study I** and **II** have mostly found depression-related alterations in the cognitive aspects of emotional information processing. This includes altered cognitive processing of ironic conversations (P600 modulation to irony, reflecting efforts on resolving the semantic conflicts, was imbalanced between the hemispheres) in **Study I**, and less synchronized valence ratings of sad movie clips in **Study II**. However, for the indexes of emotional reactivity, group differences were observed only in the funniness ratings of all conversations. Compared to non-depressed participants, the depressed participants did not show significant alterations in facial EMG to ironic and non-ironic stimuli in **Study I**, or in EDA responses to emotional movie clips in **Study II**.

For the cognitive processing of emotional information, previous studies have reported depression-related impairments, such as attentional bias to negative stimuli, persisting ruminative thoughts about oneself and surroundings, difficulties disengaging from self-related negative information, and difficulties in emotion regulation. For **Study I**, group differences in P600 amplitudes were expected because depressed participants also showed deficits in mentalizing and executive functions, verbal fluency, and verbal memory, which have been reported to be associated with irony processing. However, the results of **Study I** showed that depressed and non-depressed participants did not differ in their cognitive capabilities that measuring these aspects. Hence, the underlying mechanism of the hemispheric imbalance of P600 modulation to ironic punchlines in the depressed group is unclear but may be associated with the dysfunction of the right hemisphere in depression (Atchley et al., 2003; Hecht, 2010; Kalatzis et al., 2004). This inference, as well as its significance to behavior, requires further investigation.

Regarding another finding of the dissertation in relation to the cognitive processing of emotional information in depression, the valence rating in **Study II** should be considered, as participants were instructed to evaluate the valence of movie contents rather than their subjective emotions toward movie clips. According to the results of **Study II**, depressed participants did not show alterations in the mean values of valence ratings but only in the synchrony of valence ratings across participants. One explanation for the lack of group differences in mean valence ratings may be related to how the valence ratings were recorded and how the mean valence ratings were analyzed. In **Study II**, participants were instructed to rate the valence of the scenes continuously rather than rate the whole movie clip at once, and the mean valence ratings were computed as an average of all the dynamic ratings within each movie clip. However, movies usually contain many scenes in sequence, and not all scenes are extremely positive or negative. It is possible that when rating the whole movie clip at once, the participants would remember the most intensive parts of scenes, which may be overrepresented in the values of their ratings; therefore, the group differences might be more easily found for the mean values than for dynamic rating of valence. In **Study II,** the lower ISC in sad movie clips in depressed participants suggests that negative emotional content, especially sad content, could lead to individual variability in the valence rating of movie content within the depressed group. This may be because sad content could evoke self-related rumination and unpleasant memories in depressed participants, which could shift their attention away from the movie content.

Concerning the indexes of emotional reactions, in **Study I** and **II**, group differences were not observed in facial EMG and EDA responses, which reflects participants' emotional responses regarding valence and arousal, respectively. The lack of group differences in these emotion-related automatic responses in **Study I** and **II** could be related to the clinical status and severity of depression, as not all of the depressed participants were clinically depressed, and some of them had several symptoms that corresponded to mild depression. Furthermore, as stated in the limitations, for **Study I**, both ironic praise and ironic criticism were applied, and most previous studies have reported positive reactions to ironic criticism (Dews et al., 2009; Thompson et al., 2016). Regarding **Study II**, although movies have been considered a strong stimulus to elicit emotions, and previous studies have found differences in self-reported emotional reactions and psychophysiological responses to movies between depressed patients and healthy participants (Kaviani et al., 2004; Rottenberg et al., 2002, 2005), the depressed and control groups did not differ in their EDA responses. One possible reason may be related to the stimuli, as the missing captions and audio could make it difficult to interpret and engage with the storyline, thus reducing the participants' emotional reactions to the movies. Taken together, the features of the stimuli and the emotional intensity that the participants perceived might have affected the results.

For **Study III**, the findings of P1 responses provide an important reference for future depression-related studies. In depression, enlarged P1 amplitudes to sad facial expressions compared to neutral expressions were observed in the early automatic processing of faces (Dai & Feng, 2012; Ruohonen et al., 2020; Zhang et al., 2016). Furthermore, a previous study (Ruohonen et al., 2020) found that the amplitude of P1 to sad faces was state-dependent, as the amplitudes of P1 differential responses to sad faces were reduced when the participants had fewer depressive symptoms. **Study III** applied a similar paradigm as Ruohonen et al. (2020), however, in **Study III**, the P1 modulation to sad deviant faces was not observed in healthy participants in depressed mood. Accordingly, it seems that the induced depressed mood and depressive state do not similarly affect P1. As suggested by Ruohonen et al. (2020), differences in P1 amplitudes to sad faces between recovered and non-recovered depressed participants were not found, and thus, the P1 could indicate the state of depressive illness rather than be a biomarker for a depression diagnosis. However, the sample size of the two groups (recovered and non-recovered) was small, which may have reduced the statistical power in their study. Therefore, future studies could directly compare P1 to sad faces in clinically depressed patients and healthy participants in a depressed mood. If the results are repeated, the P1 amplitude to sad faces in automatic deviance detection may have the potential to be developed toward biomarker use for a depression diagnosis.

In conclusion, this dissertation applied novel methodologies to obtain multimodal information on human emotional information processing, which has rarely been used in previous studies of depression. The findings from this dissertation show evidence that the cognitive processing of different types of emotional dynamic stimuli is altered in people with depressive symptoms. The alterations in depression were here observed to the slow, effortful, and conscious processes (e.g., interpreting implied ironic meanings, determining the valence of movie contents) than to the fast and automatic processes (e.g., automatic facial reactivity to ironic conversations). This is corroborated by electrical brain activity in relation to irony comprehension and the synchronization of valence ratings of sad movie clips. Furthermore, this dissertation provides the first evidence that depressed mood affects healthy people's preattentive change detection of faces. These brain activity results provide a hint for future studies exploring biomarkers for diagnosing depressive disorder.

YHTEENVETO (SUMMARY)

Masennusoireet ja masentunut mieliala vaikuttavat tunnepitoisten ärsykkeiden kognitiiviseen käsittelyyn: todisteita psykofysiologisista ja käyttäytymisen mittareista

Tunnepitoisen tiedon käsittely, kuten ympäristön ärsykkeiden havaitseminen ja tulkinta, on tärkeää ihmisen selviytymiselle, sosiaaliselle vuorovaikutukselle ja ihmisten väliselle kommunikaatiolle. Joissakin mielialahäiriöissä, kuten masennusoireyhtymässä, tunnepitoisen tiedon käsittely on muuntunutta. Masennuksessa ilmenee esimerkiksi lisääntynyttä valikoivaa tarkkaavuutta negatiivisiin ärsykkeisiin, itseen ja ympäristöön kohdistuvia ruminatiivisia ajatuksia ja tunteiden säätelyn vaikeuksia. Aiemmat tutkimukset ovat käyttäneet pääasiassa staattisia ärsykkeitä kuten kuvia selvittääkseen masennukseen liittyviä tiedonkäsittelyn muutoksia. Ei ole kuitenkaan riittävästi selvitetty, kuinka masentuneet henkilöt reagoivat dynaamisiin tunnepitoisiin ärsykkeisiin kuten keskusteluihin tai elokuviin, jotka ilmentävät luonnollisen elämän tilanteita. On myös epäselvää, kuinka masentunut mieliala vaikuttaa tunnepitoisen tiedon käsittelyyn terveillä ihmisillä.

Tämä väitöskirjatyö pyrki syventämään nykyistä ymmärrystämme masennusoireiden vaikutuksesta tunnepitoisiin ärsykkeisiin reagoinnista. Tutkittaville esitettiin dynaamisia kuulo- ja näköärsykkeitä eli puhuttuja keskusteluja ja elokuvakohtauksia samalla kun tutkittavien käyttäytymisvasteita ja kehollisia reaktioita mitattiin monitasoisesti. Lisäksi tutkittiin terveillä koehenkilöillä ovatko aivovasteet tunnepitoisiin kasvokuviin erilaisia surullisessa ja neutraalissa mielialassa.

Osatutkimuksessa I selvitettiin ironian ymmärtämistä ja ironiaan liittyviä tunnereaktioita masentuneilla ja ei-masentuneilla kontrollikoehenkilöillä. Käyttäytymisvasteita, kasvolihasaktiivisuutta corrugator supercilii- ja zygomaticus major-lihasten alueilla ja aivojen sähköisiä jännitevasteita mitattiin vasteena ironisiin ja ei-ironisiin keskusteluihin. Koehenkilöt arvioivat ironiset ärsykkeet valenssiltaan positiivisemmiksi (hauskemmiksi) ja ne aiheuttivat molemmissa koehenkilöryhmissä suuremmat hymyilyä ilmentävät vasteet zygomaticus major-lihaksen alueella verrattuna ei-ironisiin ärsykkeisiin. Valenssiarviot olivat kuitenkin kokonaisuudessaan ironisten ja ei-ironisten ärsykkeiden osalta masennusryhmässä negatiivisempia kuin kontrolliryhmässä heijastaen vähäisempää emotionaalista reagoivuutta masennusryhmässä. Aivovasteissa löydettiin molemmissa ryhmissä suurentuneet N400- ja P600-vasteet ironisiin keskusteluihin verrattuna ei-ironisiin keskusteluihin, minkä voi arvella heijastavan kognitiivista ponnistelua ironisten merkitysten tulkintaan liittyen. Ryhmäero löydettiin P600-vasteessa: masennusryhmässä suurentunut P600-vaste ironiaan painottui oikeaan aivopuoliskoon, kun taas kontrolliryhmässä se oli samansuuruinen molemmissa aivopuoliskoissa.

Masennukseen liittyvistä aivoaktiivisuusmuutoksista huolimatta, muutoksia ei löytynyt emotionaalisissa reaktioissa erityisesti ironiaan liittyen.

Osatutkimus II tarkasteli eroja masentuneiden ja ei-masentuneiden koehenkilöiden välillä dynaamisissa valenssiarvioissa (positiivinen – negatiivinen elokuvan sisältö) ja ihon sähkönjohtavuudessa vasteena surullisiin, pelottaviin ja hauskoihin elokuvakohtauksiin. Keskeisenä tarkastelussa oli myös valenssiarvioiden synkronia eli yksilöiden arvioiden yhteneväisyys ryhmien sisällä. Dynaamisten arvioiden synkroniaa tutkittiin käyttämällä yksilöiden välisen korrelaation menetelmää. Tutkimustulokset eivät osoittaneet ryhmäeroja valenssiarvioissa tai ihon sähkönjohtavuudessa, kun tarkasteltiin keskiarvovasteita eri elokuvatyyppeihin (surullinen, pelottava, hauska). Yksilöiden välinen yhteneväisyys valenssiarvioissa oli pienempi masennusryhmässä kuin kontrolliryhmässä erityisesti surullisiin elokuviin. Tämä saattaa ilmentää masentuneiden tutkittavien vähäisempää ärsykesidonnaista prosessointia, kun he katselevat surullisia elokuvia. On mahdollista, että elokuvat herättävät masentuneilla henkilöillä enemmän esimerkiksi itseen kohdistuvaa ruminaatiota tai epämieluisia muistoja, jotka vievät huomion pois elokuvasta.

Osatutkimus III selvitti kuinka terveille koehenkilöille laboratoriossa tuotettu surullinen mieliala, verrattuna neutraaliin mielialaan, vaikuttaa esitietoiseen muutoksen havaitsemiseen tunnepitoisissa kasvoissa. Koehenkilöille tuotettiin surullinen ja neutraali mieliala erillisinä päivinä käyttämällä musiikkia ja kirjoitettuja lauseita, joita tutkittavien tuli lukea. Molempina päivinä mielialan tuottamisen jälkeen tutkittaville esitettiin surullisia ja iloisia kasvokuvia neutraalien kasvokuvien joukossa samalla kun tutkittavat keskittyivät matemaattiseen laskutehtävään. Laskutehtävän tarkoituksena oli suunnata tutkittavien huomio toisaalle, jotta esitietoista muutoksen havaitsemista kasvokuvissa voitiin tutkia. Aivojen sähköiset jännitevasteet ja erityisesti niiden erotusvasteet (tunnepitoinen – neutraali kasvonilme), jotka ilmentävät automaattisen muutoksen havaitsemisen eri vaiheita, määritettiin ja niitä verrattiin neutraalissa ja surullisessa mielialassa. Tulokset osoittivat mielialan vaikutuksen N170-erotusvasteeseen, joka oli suurempi tunnepitoisiin kasvoihin neutraalissa kuin surullisessa mielialassa. Ennakoituja mielialavaikutuksia ei löydetty P1- tai P2-vasteen amplitudista eikä mikään tutkitun aivovasteen latensseista. Tulokset osoittavat, että surullinen mieliala vaikuttaa häiritsevästi esitietoiseen muutoksen havaitsemiseen ja erityisesti kasvojen rakenteen aivotason koodaamiseen, jota N170-vaste ilmentää.

Väitöskirjassa sovellettiin uusia menetelmiä monitasoisen tiedon tuottamiseksi ihmisen tiedonkäsittelyn tutkimiseksi. Tallaista useiden menetelmien yhdistelmää on vain harvoin käytetty aiemmissa tiedonkäsittelyyn liittyvissä tutkimuksissa masentuneilla tutkittavilla. Yhteenvetona voidaan todeta, että tämän väitöskirjatutkimuksen tulokset osoittavat, että tunnepitoisten ärsykkeiden kognitiivinen prosessointi on muuntunutta ihmisillä, joilla on masennusoireita. Näin voidaan olettaa ironian ymmärtämiseen liittyvien aivoaktiivisuuden mittauksien ja elokuvien katselunaikaisien valenssiarvioiden synkronian perusteella. Lisäksi väitöskirja tarjoaa alustavaa näyttöä siitä, että surullinen mieliala vaikuttaa terveiden henkilöiden esitietoiseen muutoksen havaitsemiseen kasvonilmeissä. Nämä surulliseen mielialaan liittyvät aivovastetulokset tarjoavat vertailukohdan tulevaisuuden tutkimuksille, joissa pyritään löytämään objektiivisia menetelmiä masennuksen diagnosointiin.

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ORIGINAL PAPERS

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ELECTRICAL BRAIN ACTIVITY AND FACIAL ELECTROMYOGRAPHY RESPONSES TO IRONY IN DYSPHORIC AND NON-DYSPHORIC PARTICIPANTS

by

Xueqiao Li, Janne Pesonen, Elina Haimi, Huili Wang, & Piia Astikainen, 2020

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Electrical brain activity and facial electromyography responses to irony in dysphoric and non-dysphoric participants

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ABSTRACT

We studied irony comprehension and emotional reactions to irony in dysphoric and control participants. Electroencephalography (EEG) and facial electromyography (EMG) were measured when spoken conversations were presented with pictures that provided either congruent (non-ironic) or incongruent (ironic) contexts. In a separate session, participants evaluated the congruency and valence of the stimuli. While both groups rated ironic stimuli funnier than non-ironic stimuli, the control group rated all the stimuli funnier than the dysphoric group. N400-like activity, P600, and EMG activity indicating smiling were larger after the ironic stimuli than the non-ironic stimuli for both groups. Further, in the dysphoric group the irony modulation was evident in the electrode cluster over the right hemisphere, while no such difference in lateralization was observed in the control group. The results suggest a depression-related alteration in the P600 response associated to irony comprehension, but no alterations were found in emotional reactivity specifically related to irony.

1. Introduction

Generally, irony has been considered to be evoked from a comparison: a disparity between what is said and what is intended to be said (Grice, 1975). Imagine that you are on a sailing trip. Your boat is not moving, as there is no wind. The trip is becoming boring because the condition has remained windless for several hours. Your friend says, “What an exciting day for sailing!” This comment, which contrasts with the existing feeling, is a good example of an ironic statement.

The present study aimed to investigate irony comprehension and irony-related emotional reactions, and identify possible differences between dysphoric (individuals with elevated number of depressive symptoms) and non-dysphoric participants in these aspects. Facial electromyography (EMG) and event-related potentials (ERPs) were used to measure emotional facial expressions and cognitive processing related to irony, respectively. Differences in the irony-related emotional reactions and irony comprehension were expected between dysphoric and control groups, because previous studies have found alterations in emotional reactivity (for reviews, see Bylsma et al., 2008; Cusi et al., 2012), and cognitive function (for a review, see Gotlib and Joormann, 2010), such as verbal fluency (Henry and Crawford, 2005) and mentalizing (Bora and Berk, 2016) in clinical and preclinical depression. Impairments in irony comprehension have been found in schizophrenia and schizotypy (e.g., Del Goleto et al., 2016; Herold et al., 2018; Varga et al., 2013); however, whether or how irony comprehension is altered in depressed individuals has not yet been explored.

1.1. Emotional reactions to irony

Irony is widely used in everyday conversations to fulfill an implied goal in social communications. It can elicit positive feelings in the receiver, such as inducing amusement and humor (Calmus and Caillies, 2014; Dews, Kaplan, and Winner, 1995; Dynel, 2009; Martin, 2010; Matthews, Hancock, and Dunham, 2006), but it can also increase or reduce the listeners’ negative feelings (Leggitt and Gibbs, 2000; Toplak and Katz, 2000). Relationship between conscious valence ratings and emotional reactions to irony can also be complex: when irony was directed towards the participants, behavioral evaluations showed that the participants perceived the ironic stories to be more humorous than the literal ones, but the ironic stories also elicited more negative emotions than the literal stories in the participants (Akimoto et al., 2014).

In addition to behavioral ratings, psychophysiological reactivity, such as facial muscle activity (i.e., facial EMG), is of interest when attempting to understand irony-evoked emotions (Thompson, Mackenzie, and Leuthold, 2016). Facial reactivity in the zygomaticus major muscle (cheek area) and in the corrugator supercilii muscle (brow region) is an index of emotional expressions corresponding to smiling and frowning, respectively (Van Boxtel, 2010; Dimberg, 1990). Facial EMG has been

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measured in response to humor (e.g., Fiacconi and Owen, 2015), but only a few studies have investigated facial EMG responses to irony. In one study, facial EMG was measured in relation to written ironic praise and criticism, with and without emoticons (Thompson et al., 2016); it was found that ironic criticism reduced frowning and enhanced smiling in comparison to literal criticism, indicating weakening of the negative emotional response due to irony. However, no previous studies have investigated facial reactivity to spoken ironic statements.

1.2. Theoretical models and empirical evidence of irony comprehension

Different models have been used to explain irony comprehension (for a review, see Attardo, 2000). The one-stage model (also called the direct access view, e.g., Gibbs, 2002) in general proposes that the figurative language (written or oral), such as irony, can be accessed directly as the literal language. In contrast, two-stage models, such as the traditional standard pragmatic view (e.g., Grice, 1975) and the graded salience hypothesis (e.g., Giora and Fein, 1999; Giora, 2003), suggest that irony comprehension requires access to both literal and ironic meanings. The former expects that, in irony comprehension, one should first access the literal meaning, detect and distinguish the discrepancy in the semantic context, and then reconstruct the information to retrieve the intended ironic meaning. The graded salience hypothesis assumes that there are two stages in irony comprehension, but it makes no explicit hypothesis about their sequential order.

Most empirical studies have supported the two-stage processing of irony. Behavioral reading paradigms have shown that ironic comments require longer reading times than literal ones (Giora, Fein, and Schwarts, 1998; Schwoebel, Dews, Winner, and Srinivas, 2000). Along the same lines, in eye tracking studies (e.g., Filik and Moxey, 2010; Kaakinen et al., 2014), the participants' fixation times were longer, and they spent more time in rereading ironic sentences than non-ironic sentences. These findings can be interpreted as evidence of additional processing demands related to irony, thus supporting the two-stage models.

The cognitive processes in irony comprehension have been investigated using time-sensitive ERP method in healthy participants (e.g., Balconi and Amenta, 2008; Baptista et al., 2018; Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014; Regel et al., 2011, 2014; Spotorno et al., 2013). These studies have shown that comprehending ironic sentences requires additional inferential processes in comparison to non-ironic sentences; this finding is consistent with the traditional standard pragmatic view (e.g., Regel et al., 2011) or the graded salience hypothesis (e.g., Filik et al., 2014). In many of the studies (Cornejol et al., 2007; Filik et al., 2014; Caillies et al., 2019), two ERP components, N400 and P600, were elicited consecutively, and both were larger in amplitude for irony than non-irony, reflecting the two-stage processing of irony comprehension.

The N400 is an ERP component that is triggered by semantic violations and modulated by the context given to the statement (for reviews, see Kutas and Federmeier, 2011; Lau et al., 2008). It is observed as a shift towards negative polarity at 200–600 ms after a stimulus onset at the centro-parietal electrode sites (e.g., Kutas and Federmeier, 2000; Kutas and Hillyard, 1980; Van Petten and Luka, 2006). N400 amplitude modulations have been interpreted to reflect either an additional effort in semantic integration (Kutas and Federmeier, 2011; Lau et al., 2008) or the difficulty of retrieving the stored knowledge associated with the stimulus (Brouwer et al., 2012). Larger N400 amplitude has been observed during the processing of nonliteral language, for instance, humor (e.g., Coulson and Kutas, 2001; Feng, Chan, and Chen, 2014; Marinkovic et al., 2011) and irony (Baptista et al., 2018; Caillies et al., 2019; Cornejol et al., 2007; Filik et al., 2014). Several studies (Cornejol et al., 2007; Filik et al., 2014; Caillies et al., 2019) have demonstrated that the modulation of N400 reflects difficulties in integrating the meaning of an irony-related incongruent word into the context; thus, N400 modulation has been found to be one of the indicators reflecting the two-stage processing of irony. However, the findings related to irony are inconsistent, as the N400 effect is not always found in response to irony (e.g., Balconi and Amenta, 2008; Regel et al., 2011, 2014).

In contrast to the inconsistent findings on the N400 elicitation to irony, the amplitude of the P600 has been repeatedly found to be larger for ironic than non-ironic sentences (Filik et al., 2014; Regel et al., 2011, 2014; Spotorno et al., 2013). P600 is a shift towards positive polarity, reaching its maximum amplitude approximately at 600 ms latency at the centro-parietal electrode sites (for a review, see Bornkessel-Schlesewsky and Schlesewsky, 2008). It was initially observed when the participants encountered syntactic anomalies (e.g., "The woman encouraged to write a blog."; "the fancy very car") and it was interpreted as a reflection of syntactic reanalysis (e.g., Gouvea et al., 2010; Osterhout and Holcomb, 1992). The P600 effect has also been found in response to semantic violations (e.g., Nieuwland and Van Berkum, 2005; Sanford et al., 2011), which was interpreted as continued analysis to achieve conflict resolution or the updating of mental representations (for reviews, see Bornkessel-Schlesewsky and Schlesewsky, 2008; Brouwer et al., 2012; Kuperberg, 2007) in language comprehension. Increased P600 amplitude is often observed in response to irony (Filik et al., 2014; Regel et al., 2011, 2014; Spotorno et al., 2013), humor (e.g., Feng et al., 2014; Canal, et al., 2019; Shibata, et al., 2017; Marinkovic, et al., 2011) and figurative language in general (e.g., Bambini, et al., 2016). It has been suggested that the modulation of the P600 reflects the cognitive effort made when interpreting the implied meaning of nonliteral language (for irony, see e.g., Regel et al., 2011, 2014).

1.3. Depression and possible emotional and cognitive alterations related to irony comprehension

Depression is a severe mental health disorder characterized by both affective and cognitive symptoms, including sadness, tiredness, disturbances in sleep and appetite, and feelings of guilt or low self-worth (World Health Organization, 2010). Depressive individuals possess persistent mood-congruent rumination that negatively affects their ability to process emotional information (for reviews, see Gotlib and Joormann, 2010; Peckham, McHugh, and Otto, 2010). One of the most prominent features in depression is blunted reactivity to emotional stimuli (see a review, Bylsma et al., 2008), such as to pleasant pictures (e.g., Allen, Trinder, and Brennen, 1999; Dunn et al., 2004; Sloan, Strauss, and Wisner, 2001), positive words (Canli et al., 2004), and affective audiovisual videos (Rottenberg et al., 2002; 2005).

Concerning nonliteral language processing, humor comprehension has been found to be altered in depression (Uekermann et al., 2008). Depressed patients performed worse than the controls in selecting correct punchlines to humorous discussions, and they rated the humorous punchlines as being less funny than the controls (Uekermann et al., 2008). Alterations in humor processing have been associated with impairments in executive functions and mentalizing in depressed participants (Bora and Berk, 2016; Uekermann et al., 2008). Deficits in mentalizing have also been suggested to underlie the impairments in irony processing in individuals with schizophrenia and schizotypal personality disorder (e.g., Del Goleto et al., 2016; Herold et al., 2018; Varga et al., 2013), but no studies have investigated irony processing in people with depression. In addition to mentalizing, irony comprehension requires verbal fluency and verbal memory (e.g., Gaudreau et al., 2015; Spotorno et al., 2012), both of which are impaired in depression (Basso and Bornstein, 1999; Henry and Crawford, 2005). Based on the previous findings on the blunted emotional reactions and the cognitive deficits in depression, it is very likely that both emotional reactions to ironic stimuli and the cognitive processing aspect of irony are affected by depressive symptoms.

1.4. The present study

In the current study, conversational irony was investigated by presenting the participants with spoken dyadic conversations that resembled the natural occurrence of irony in the daily life. The keywords in the conversations were allocated to different positions, which made the stimuli less predictable and more naturalistic in comparison to previous studies in which the keyword was always presented as the last word of the sentence (e.g., Filik et al., 2014; Regel et al., 2011, 2014). The conversations were combined with pictures that were either congruent or incongruent with the statements; thus, the conversation was defined as either non-ironic or ironic, respectively. This approach allowed the responses to be contrasted to the same spoken sentences (non-ironic vs. ironic), avoiding the confounding caused by possible differences in the physical features of the stimuli, e.g., the position of the keywords.

In the first measurement day, facial EMG (corrugator and zygomaticus activity) and ERPs (N400 and P600) were measured while participants were passively observing the stimuli. To complement these measurements, evaluations of the congruency of the picture-sentence pairs and valence ratings (unpleasant vs. funny) of the conversations were also recorded in a separate measurement session on a different day. These data were collected on different days, as the rating task can influence participants' spontaneous emotional reactivity (Hutcherson et al., 2005). The use of relatively naturalistic stimulus conditions and a combination of different measures provide a comprehensive understanding of irony processing and how depressive symptoms possibly affects cognitive and/or emotional aspect of irony processing.

We hypothesized that the control participants would rate the ironic stimuli funnier than the non-ironic stimuli, because most of the previous studies have demonstrated this (Akimoto et al., 2014; Calmus and Caillies, 2014; Dews et al., 1995). However, it is also possible that the ironic stimuli would be rated as more unpleasant than the non-ironic stimuli, because several stimulus- and participant-related factors might affect the emotional reactions to irony, but these are not well known (Leggitt and Gibbs, 2000). Regardless, the ratings should be to the same direction with the EMG responses; that is, if participants rate ironic stimuli as more funny than non-ironic stimuli, a higher zygomaticus reactivity, reflecting smiling (Van Boxtel, 2010), should also be observed to ironic comparing to non-ironic stimuli; and if participants rate ironic stimuli more unpleasant than non-ironic stimuli, a higher activity in the corrugator supercili, reflecting frowning (Van Boxtel, 2010; Dimberg, 1990), should be observed.

Due to biases in emotional information processing in depression (e.g., Beck, 1967, 2008; Bylsma et al., 2008; Gotlib and Joormann, 2010; Xu et al., 2018), the valence ratings of the ironic stimuli were expected to be more negative for the dysphoric group than the control group. We also expected, based on previous findings of low emotional reactivity to both positive and negative stimuli in depression (e.g., Bylsma et al., 2008), that the difference in facial EMG responses between the non-ironic and ironic stimuli would be smaller in the dysphoric group than the control group. Since no difficulty related to detecting semantic violation is expected in the dysphoric group (Deldin et al., 2006; Klumpp et al., 2010), it was hypothesized that the accuracy of the congruency detection of the picture-sentence pairs should be high in both groups.

For the ERP responses, we hypothesized that an N400-like effect (Filik et al., 2014) would be similar in the dysphoric and control groups, as reported in previous studies where the depression group and the controls showed similar N400 amplitudes in semantic processing of congruent and incongruent sentence endings (Deldin et al., 2006; Klumpp et al., 2010). However, it is possible that the N400-like activity would not be elicited, as the recognition of semantic incongruence may not be a necessary processing stage for irony comprehension (Balconi and Amenta, 2008; Regel et al., 2011, 2014).

In addition, we hypothesized that irony would elicit a larger P600 response than non-ironic stimuli, as has been consistently reported in previous irony studies (e.g., Filik et al., 2014; Regel et al., 2011, 2014), and it is possible that the P600 response would be decreased in amplitude in the dysphoric group. While no previous studies have investigated the P600 response to ironic stimuli in depressed participants, one study has shown that P600 elicited in a working memory task can be used to distinguish between depressed and control participants through using a machine learning approach (Kalatzis et al, 2004). In schitzotypyal personality disorder, a decrease in P600 modulation in relation to irony has been associated mainly with difficulties in mentalizing (Del Goleto et al., 2016). Since there is also a deficit in mentalizing (Bora and Berk, 2016; Inoue et al., 2004; Lee et al., 2005) and in other cognitive functions in depression, such as verbal fluency and verbal memory (Basso and Bornstein, 1999; Henry and Crawford, 2005), it is possible that a decrease in P600 will be found in the dysphoric group.

2. Materials and methods

2.1. Participants

As there was no previous study investigating cognitive and affective aspects of irony processing in control and dysphoric or depressed participants, sample size in the present study was estimated based on a standard medium effect size (η_p^2 = 0.060; Cohen, 1988). Power analysis, conducted with G*Power 3 (Faul et al., 2007), showed a requirement of 17 participants in each group (control and dysphoric) with a statistical power of (1 - β) = 0.80 and a significance level of alpha = 0.050.

Two groups of volunteers were recruited in this study: dysphoric group and control group. Potential participants were informed about the study via email lists from the University of Jyväskylä and by distributing advertisement flyers in Jyväskylä. The study protocol was in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the University of Jyväskylä. All the participants gave written informed consent before the measurements started.

For the dysphoric group, participant with current depressive symptoms (13 or higher score in the Beck's Depression Inventory-II; BDI-II; Beck et al., 1996) were included. The participants in the control group had a BDI-II score below 10. All participants were right-handed native speakers of Finnish, with normal or corrected-to-normal vision and normal hearing. Participants were included if they reported no current or previous neurological or psychiatric disorders, except depression or anxiety disorders in the dysphoric group.

In total, twenty-four dysphoric participants and twenty-eight control participants (age range 18–40 years) volunteered for the study. Seven participants were excluded from the dysphoric group and another seven participants were excluded from the control group according to the exclusion criteria or because of extensive ocular artefacts in their EEG data. Therefore, 17 dysphoric participants (3 male, 14 female) and 21 control participants (6 male, 15 female) were included in the final sample. Sixteen out of 17 dysphoric participants reported having an existing diagnosis of depression. One of them had been diagnosed with a mixed anxiety and depressive disorder. Demographics and clinical information of the dysphoric and control group are presented in Table 1.

There was no significant difference in age, gender or education (all *p*-values $>$ 0.254) between the two groups (Table 1). The cognitive capabilities were also evaluated in the dysphoric and control groups. The two groups did not differ in any of the cognitive tests measuring memory, executive functions and verbal fluency. Details of the cognitive test scores are shown in the Supplementary Table 1.

Table 1
Demographics and clinical measures. Statistics show independent *t*-test or x^2 test values investigating the group differences.

Characteristics		DYS (n = 17)	CTRL (n = 21)	Statistics
Age (year)	Mean	24.82	23.52	$t(36) = 1.15, p = 0.255$
	SD[range]	3.73 [21–33]	3.20 [19–32]	
Level of Education[a]	Medium	9	9	$x^2(1) = 0.38, p = 0.536$
	High	8	12	
Gender	Male	3	6	$x^2(1) = 0.62, p = 0.431$
	Female	14	15	
BDI-II	Mean	23.71	2.52	$t(36) = 13.48, p < 0.001$
	SD[range]	6.59 [14–39]	2.64 [0–9]	
Severity of Depression[b]	Moderate (F32.1)	12	Na	Na
	Severe (F32.2)	1	Na	Na
Time of Diagnosis	Within six months	3	Na	Na
	Within one year	4	Na	Na
	Over one year	9	Na	Na
Depression Medication[c]	SSRI	5	Na	Na
	SNRI	1	Na	Na
	Other	4	Na	Na

Note. DYS = dysphoric group, CTRL = control group, SD = standard deviation, BDI-II = Beck's Depression Inventory, Second Edition.
[a] Medium = high school or vocational school, High = university.
[b] Depression severity based on participants self-report on their diagnosis. The diagnosis of depression was based on the International Classification of Diseases and Related Health Problems, 10th Revision (ICD-10; World Health Organization, 2010) criteria. There is missing information related to disease severity from three participants, and one participant did not have diagnosis.
[c] SSRI = selective serotonin reuptake inhibitor, SNRI = serotonin and norepinephrine reuptake inhibitor, Other = other antidepressant medication.

2.2. Procedure

Psychophysiological and behavioral measurements for each participant were conducted on two separate days.

On the first measurement day, facial EMG and EEG data were collected. A set of cognitive tests (see list in Supplementary Table 2) were conducted on the same day after the recording of the psychophysiological signals. The participants were informed that they were going to be presented with conversations between two people, along with related pictures. The purpose of the study (i.e., irony processing) was not revealed until the participants completed the whole study. During the measurement, participants were seated in a soundproofed room while the stimuli were presented. No task was designed for the participants during the first day's measurement. Participants were instructed to focus on the stimuli and avoid frequent eye blinks and unnecessary movements during the recording.

On the second measurement day, participants were seated at the same room. Congruency evaluation and valence rating (unpleasant vs. funny) for picture-sentence pairs were collected. The Humor Styles Questionnaire (HSQ; Martin et al., 2003) was filled out after the behavioral task. The analysis and results of Humor Styles Questionnaire are presented in Supplementary materials.

2.3. Stimuli

The same stimuli were applied for both facial EMG/EEG and behavioral measurements. Stimuli in each trial consisted of an introductory sentence, a contextual picture and a commenting sentence. The sentences were spoken in Finnish, with a neutral intonation by two female and two male speakers. The spoken conversations were presented from a ceiling loudspeaker above the participants, approximately one meter from participants' ears. The contextual pictures were taken from the internet and the International Affective Picture System (IAPS; Lang et al., 2008). They were color pictures depicting real-life scenes and presented to a screen with a resolution of 1024 × 768 pixels to a 23-inch screen (Asus VG236H, 1920 × 1080 pixels) approximately one meter in front of the participant.

The presentation of each experimental trial is illustrated in Fig. 1. First, an introductory sentence was presented as a setup for the conversation. Next, a contextual picture was displayed on the center of the screen. Then, a fixation mark appeared to the screen, after which a spoken commenting sentence was presented together with the fixation mark. The commenting sentence was spoken by a different person than the introductory sentence providing a comment to the introductory sentence. The same conversations were presented twice during the experiment: with a picture which provided a congruent context to the commenting sentence (non-ironic condition) and with a picture which provided an incongruent context to the commenting sentence (ironic condition). The inter-trial interval (from the offset of the last word in the commenting sentence to the onset of the first word in the introductory sentence) was randomized between 4000 and 4200 ms. Identities of the four speakers in the audio files changed trial-by-trial, and the keywords were allocated at different positions of the commenting sentences making the sentences more variable and less predictable.

Both negative (50%) and positive (50%) valence keywords were applied. The commenting ironic sentence with a positive keyword can be defined as ironic criticism and ironic sentence with negative keyword can be defined as ironic praise. However, due to the limited number of trials in each sub-type, we did not analyze possible effects related to different sub-types.

In total, 100 conversations with two contrasting pictures were created. A pilot study aimed to validate the agreement in the congruency rating was conducted before the formal experiment. Seven participants rated one half of the conversations, and six participants rated the other half. These participants were different from the participants of the actual ERP study. Ten conversations were excluded from the stimuli after the pilot study because the accuracy of congruency in each was < 95%.

Therefore, 90 conversations with two contrasting pictures (90 trials for ironic and non-ironic conditions, respectively) were applied in the EMG and EEG measurement. They were divided into four blocks of 45 trials. Stimulus presentation order was pseudorandom: the ironic and non-ironic stimuli were presented in a random order, but to avoid immediate repetitions, the same conversations were separated with at least 45 other conversations. In order to keep the measurement time reasonable and participants better focused on the task at hand, for the measurement of the behavioral responses participants were presented with a half of the same stimuli they were presented in the EMG and EEG measurement: a half of the participants rated the first two stimulus blocks, and the other half rated the last two stimulus blocks applied in the EMG and EEG measurement. For all the measurements, the presentation of the stimuli was controlled by E-Prime 2.0 software

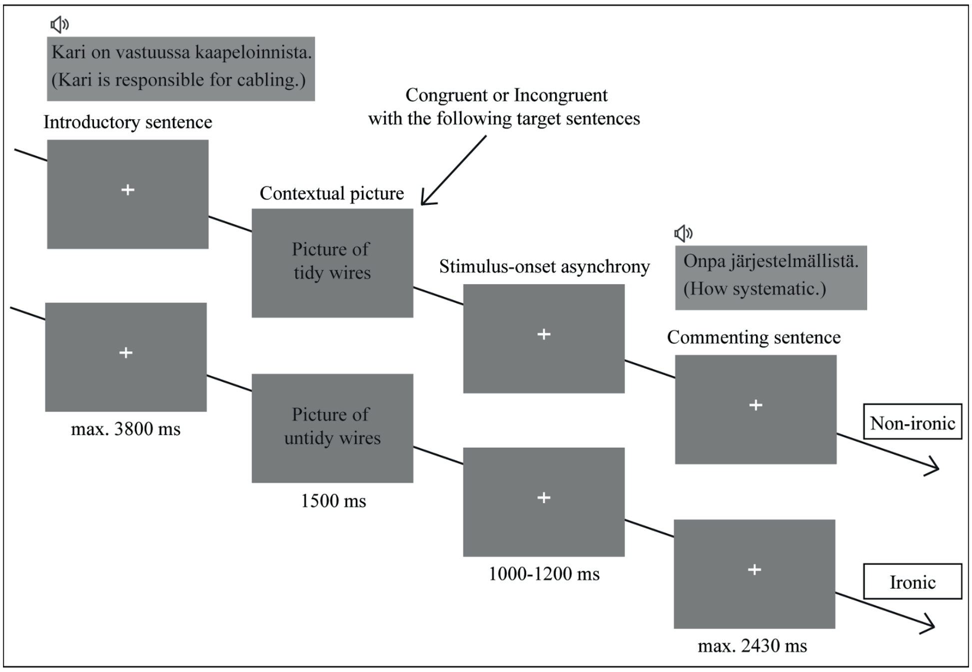

Fig. 1. An example of one pair of trials. The sentences were spoken in Finnish, but for illustrative purposes, the translations are provided here. The changes of the contextual pictures brought different conditions (non-ironic or ironic), while the commenting sentences were always the same for each non-ironic and ironic pair.

(Psychology Software Tools, Inc., Sharpsburg, PA, USA).

2.4. Facial EMG and EEG data

2.4.1. Measurement of facial EMG and EEG data

For facial EMG responses, data were recorded continuously with two disposable bipolar electrode pairs (Ag/AgCl), and in each pair, there was 0.5 cm distance between the electrodes. Pads with disinfectant were used to clean the skin in contact with the electrodes. The bipolar electrodes were placed on the right side of each participant's face, one over the corrugator supercilii muscle region (above the eyebrow) and another one over the zygomaticus major muscle region (around the cheek).

For EEG recording, a 128-Channel Net (HydroCel Geodesic Sensor Net, Electric Geodesic Inc, USA) was applied. The vertex electrode (Cz) was used as the online reference electrode.

Continuous facial EMG and EEG signals were both recorded simultaneously by a NeurOne system (Bittium Biosignals Ltd, Kuopio, Finland). All signals were recorded using AC mode at a sampling rate of 1000 Hz and were filtered online with a high cut-off of 250 Hz.

2.4.2. Analysis and statistics for facial EMG data

Facial EMG responses were pre-processed and analyzed according to a previous study (Thompson et al., 2016). The facial EMG data were first filtered with a 20–400 Hz band-pass filter (24 dB/octave) and a 50 Hz notch filter in BrainVision Analyzer 2.1 (Brain Products GmbH, Munich, Germany). Then, facial EMG data were segmented into 4400-ms epochs, starting from 400 ms before the onset of keywords. After this, a custom MATLAB script (MATLAB, R2015b, version 8.6.0) was used to further process the data. A rectified facial EMG segment was omitted if the amplitude was > 250 μV in any of the time points. Then, each facial EMG segment was computed into 11 consecutive 400-ms time windows. The facial EMG activity of 400-ms before each keyword was regarded as a baseline for each segment, and for each participant, the facial EMG amplitude was presented as a percentage relative to the baseline.

In order to reduce the levels of the time windows for analysis of variance (ANOVA; Akechi et al., 2013), facial EMG amplitude was averaged over a 1200-ms time window. The percentage of mean amplitude relative to the baseline was calculated for three intervals: 0–1200 ms (Time 1), 1200–2400 ms (Time 2) and 2400–3600 ms (Time 3) after the onset of the keyword. The values for facial EMG were analyzed separately for facial reactivity in the zygomaticus major muscle and in the corrugator supercilii muscle by using three-way repeated measures ANOVAs with Stimulus type (non-ironic vs. ironic) and Time window (1 vs. 2 vs. 3) as within-subject factors and Group (control vs. dysphoric) as a between-subject factor.

2.4.3. Analysis and statistics for EEG data

EEG data were analyzed by using Brain Vision Analyzer 2.1 (Brain Products GmbH, Munich, Germany). A new reference was calculated offline as an average over all channels. The Gratton and Coles method (Gratton et al., 1983) was applied to detect and correct the interference of eye-blinks, and Channel 8, which is above the midpoint of the right eye, was chosen as the vertical electro-oculogram (VEOG) channel. Channels with an extensive amount of noise were interpolated using a spherical spline model. The EEG signal was filtered with a low cut-off of 0.1 Hz and a high cut-off of 20 Hz, accompanied by a 24 dB/octave roll-off. A 50 Hz notch filter was also applied. After this, EEG data were extracted into 1100-ms long segments relative to the onset of keywords, starting from 100 ms before the presentation of keywords. To exclude noisy segments, gradient criterion and max–min amplitude criterion were both applied. Specifically, the maximum allowed difference in amplitude between two consecutive time points was 75 μV, and the maximum allowed voltage was − 150 μV and 150 μV at an interval of 200 ms for all the channels. Segments exceeding the specified values were omitted from the averages. The mean voltage during a period of 100 ms prior to the onset of the keyword was used as a baseline for each segment. Data were averaged separately for the two stimulus types (ironic vs. non-ironic) and for each participant.

For the ERP data, two responses were analyzed: N400-like activity and P600. Similarly to a previous study (Filik et al., 2014), we use here the term N400-like instead of N400, because there was no clear peak for the observed response unlike the classical N400 (e.g., Kutas and Federmeier, 2000; Kutas and Hillyard, 1980; Van Petten and Luka, 2006).

The time windows for statistical analysis of the N400-like activity and P600 were defined a priori based on previous studies (N400-like activity: 300–500 ms after the onset of the target word, Kutas & Federmeier, 2011; P600: 500–800 ms after the onset of the target word, Bornkessel-Schlesewsky & Schlesewsky, 2008).

The selection of the electrodes for the analysis was based on cluster-based permutation statistics (Maris and Oostenveld, 2007). This data-driven method was used as a tool to restrict the number of electrodes for the subsequent analyses conducted with repeated measures of ANOVAs (see also, e.g., Hämäläinen et al., 2018; Strömmer et al., 2017). This procedure is described in Supplementary materials. According to the results of the permutation statistics, the N400-like response was analyzed from one region of interest (ROI) (the electrodes 5, 6, 7, 12, 31, 80, 106 and 112), and the P600 response was analyzed from two ROIs (Left ROI: the electrodes 50, 51, 58 and 59; Right ROI: the electrodes 91, 96, 97 and 102). Fig. 3 and Supplementary Fig. 1 depict the electrode locations.

Mean amplitude values of the N400-like activity and P600 from the pre-defined time windows and electrodes selected with cluster-based permutation tests were applied in separate statistical analyses for each component. For the N400-like activity, a two-way repeated measures of ANOVA with Stimulus type (non-ironic vs. ironic) as a within-subject factor and Group (control vs. dysphoric) as a between-subject factor was conducted. For P600 responses, a three-way repeated measures ANOVA with within-subject variables Stimulus type (non-ironic vs. ironic) and ROI (left vs. right), and a between-subject variable Group (control vs. dysphoric) was applied. For P600, whenever a three-way interaction effect (Stimulus type × ROI × Group) was revealed, two follow-up two-way repeated measures ANOVAs were conducted to investigate the interaction effect: one separately for the two stimulus types (ROI × Group) and the other separately for the two groups (Stimulus type × ROI).

2.5. Behavioral responses

2.5.1. Measurement of behavioral responses

During the behavioral testing, participants were instructed to keep both hands on the keyboard (standard Finnish QWERTY keyboard), and press buttons with their index fingers. Response buttons (C, V, B, N, M in the keyboard) were labelled and covered by stickers with numbers (-2, −1, 0, 1, 2). Participants were first asked to evaluate as quickly as possible whether the picture and the spoken commenting sentence after it were congruent or incongruent. Then participants were asked to evaluate the valence of the conversations by using a scaling of −2 to 2 by pressing buttons that were labelled: hyvin ikävä (very unpleasant) = -2; ikävä (somewhat unpleasant) = -1; siltä väliltä (between unpleasant and funny) = 0; jokseenkin hauska (somewhat funny) = 1; hyvin hauska (very funny) = 2. The valence rating was thus designed to measure especially perceived funniness of the stimuli and the opposite negative aspect. "Ikävä", the word chosen to be the opposite (the other end of the rating scale) for funny can imply that there is a certain dislikeable aspect. Even if the promptness of the responding was requested, there was no time limit for responding. Before the actual evaluation task, the participants practiced with six rehearsal stimuli, and the experimenter confirmed that participants understood the task correctly.

2.5.2. Analysis and statistics for behavioral data

As the accuracy of the congruency detection is considered as binary and categorical data (correct: 1, incorrect: 0) in the present study, a multilevel model (mixed model) was applied (Jaeger, 2008), using Mplus software (Version 8). The model included Accuracy by Stimulus type in each trial at the within-level, and Group at the between-level (with a random slope). The full-information maximum likelihood method (MLR estimation in Mplus) was conducted to estimate the parameters. This model was aimed at analyzing the interaction between the Stimulus type (non-ironic vs. ironic) and the group (control vs. dysphoric) variables. The results of detection accuracy are reported as the percentage of correct responses.

The response times for congruency detection were calculated for trials with correct responses from the onset of the keywords. In the given example (Fig. 1), "systemaattista" ("systematic") was defined as the keyword of the commenting sentence. For each participant, response times above 2.5 standard deviations from the mean response time were excluded from the analyses. As a result of the trimming procedures, approximately 2.7% of all trials for all participants were lost for the analysis of response times. Each participant had > 32 trials for each stimulus type (ironic or non-ironic) for the reaction time measure.

Each participant's mean values for response time of the congruency detection and valence rating of conversations were calculated for both stimulus types (non-ironic and ironic) and were analyzed by conducting a two-way repeated measures of ANOVA, with Stimulus type (non-ironic vs. ironic) as a within-subject factor and with Group (control vs. dysphoric) as a between-subject factor, respectively.

2.6. General information on statistics

For all ANOVA models, whenever the sphericity assumption was violated, Greenhouse-Geisser correction was applied. The *p*-values for ANOVA results are reported based on the Greenhouse-Geisser correction, but the degrees of freedom are reported as uncorrected. The significance level for all statistics was $p < 0.050$, but marginally significant ($p \leq 0.080$) interaction effects were also further studied. Significant interactions found in the ANOVAs or follow-up ANOVAs (for P600 responses) were investigated by using independent samples *t*-tests for between-subject comparisons or two-tailed paired t-tests for within-subject comparisons. Both types of t-tests were applied with a bootstrapping method using 1000 permutations (Good, 2005) as implemented in IBM SPSS Statistics 24.0 (Armonk, NY: IBM corporated). Partial eta-squared η_p^2 and Cohen's d are reported for the estimates of effect size for ANOVAs and t-tests, respectively. Cohen's d was computed using pooled standard deviations (Cohen, 1988).

Pearson's correlation coefficients (two-tailed, computed at subject level) were applied to examine the relationships between the comprehension-related variables (the N400-like activity and the P600, and accuracy of congruency detection, respectively), and between the emotion-related variables (facial EMG corrugator and zygomaticus, and valence ratings of conversation, respectively). The correlations were calculated for ironic and non-ironic stimulus conditions separately. Multiple correlations were controlled by applying false discovery rate (Benjamini and Yekutieli, 2001) at 0.050.

For exploratory purposes, the Humor Styles Questionnaire scores were applied as a covariate to original analyses conducted for valence ratings and facial EMG activity (repeated measures of analysis of covariance, ANCOVA). These measures of affective aspects of irony could be expected to be influenced by individual's humor style. Here we used the Aggressive humor style from the Humor Styles Questionnaire because irony is close to sarcasm (Kreuz and Glucksberg, 1989), which can be categorized as aggressive humor (Martin et al., 2003). Cognitive test scores were also applied as a covariate in P600 analysis, for which we found a group difference. It can be assumed that cognitive deficits can influence irony comprehension. In order to reduce variables for analysis of covariance, principal component analysis was conducted to extract factors of the cognitive tests (see, Supplementary materials). Three cognitive factors (executive function, list memory, and semantic processing) were extracted and applied separately as covariates in a two-way repeated measures ANCOVA of P600 responses. In order to explore the effect of current medication status on the behavioral responses, ERPs, and facial EMG reactivities, additional repeated measures ANCOVA analyses were also applied with Medication (medicated vs. non-medicated) as a covariate for the dysphoric group. Since there were no interaction effects with the covariates found in all the above mentioned ANCOVA analysis, we report in Results only the changes the covariates caused to the original group effects, that is, when the covariates revealed or concealed a main effect of Group or an interaction effect with it.

In addition to ANOVA/ANCOVA analyses, effect of depressive symptoms on responses were investigated with simple linear regression analyses. A simple linear regression was calculated for the whole sample with the amount of depressive symptoms (BDI-II scores) as a predictor of ERPs, facial EMG amplitudes, and behavioral evaluations separately. Results of these analyses are reported in Supplementary materials.

3. Results

3.1. Behavioral results

The results of the accuracy and the response time of the congruency detection, as well as the valence ratings of ironic and non-ironic conversations, are presented in Fig. 2.

3.1.1. Accuracy of congruency detection

The multilevel model analysis revealed a significant main effect of Stimulus type, $p = 0.007$. The detection accuracy of the incongruent stimuli ($M = 97.78\%$, $SD = 0.14$) was slightly higher than that of the congruent stimuli ($M = 96.2\%$, $SD = 0.19$). Neither the interaction effect of Stimulus type × Group nor the main effect of Group was significant (all p-values > 0.172).

3.1.2. Response time of congruency detection

The two-way repeated measures ANOVA showed no significant effects, the main effect of Stimulus type being closest to significant, $F(1,36) = 3.869$, $p = 0.057$, $\eta_p^2 = 0.097$. The response time was descriptively longer for the ironic stimuli ($M = 2041.99$ ms, $SD = 453.79$) than for the non-ironic stimuli ($M = 1992.62$ ms, $SD = 419.14$). No interaction effect of Stimulus type × Group and main effect of Group were observed (all p-values > 0.116).

3.1.3. Valence ratings of conversations

For the valence ratings of ironic and non-ironic conversations, repeated measures ANOVA revealed a significant main effect of Stimulus type, $F(1,36) = 49.404$, $p < 0.001$, $\eta_p^2 = 0.578$. Ironic conversations ($M = 0.27$, $SD = 0.42$) were rated as funnier than non-ironic conversations ($M = -0.11$, $SD = 0.31$). The main effect of group was also significant, $F(1,36) = 5.098$, $p = 0.030$, $\eta_p^2 = 0.124$. Valence ratings were more negative in the dysphoric group ($M = -0.05$, $SD = 0.42$) than in the control group ($M = 0.19$, $SD = 0.19$) over the stimulus types. Interaction effect of Stimulus type × Group was non-significant, $p = 0.112$.

3.2. Facial EMG responses results

Results of the repeated measures ANOVAs for facial EMG corrugator and zygomaticus activity are reported in Table 2. The percentages of averaged corrugator and zygomaticus activity relative to their baseline activity for each condition are shown in Fig. 3.

3.2.1. Facial EMG corrugator activity

For facial EMG corrugator activity, three-way repeated measures ANOVA with within-subject variables Stimulus type (non-ironic vs. ironic) and Time window (1 vs. 2 vs. 3), and between-subject variable Group (control vs. dysphoric) revealed that the main effect of Time window was significant, $p = 0.009$. The corrugator activity was smaller between 0 and 1200 ms ($M = 100.4\%$, $SD = 0.022$), compared with the activity in the period of 1200–2400 ms ($M = 101.3\%$, $SD = 0.032$), $t(37) = 2.599$, $p = 0.013$, d = 0.327, and with the activity during 2400–3600 ms ($M = 102\%$, $SD = 0.040$), $t(37) = 2.738$, $p = 0.009$, d = 0.495. The difference between the activity in the period of 1200–2400 ms and 2400–3600 ms was not found, $p = 0.051$. Other main effects or interactions were not found for corrugator responses (all p-values > 0.312).

3.2.2. Facial EMG zygomaticus activity

For facial EMG zygomaticus activity, three-way repeated measures ANOVA showed that the main effect of Time window was significant, $p = 0.002$. The zygomaticus activity was larger in the time window of 1200–2400 ms ($M = 105.8\%$, $SD = 0.115$) and 2400–3600 ms ($M = 105.3\%$, $SD = 0.098$), compared with the activity between 0 and 1200 ms ($M = 101.3\%$, $SD = 0.033$), $t(37) = 3.082$, $p = 0.004$, d = 0.532; $t(37) = 2.739$, $p = 0.009$, d = 0.547, respectively. There

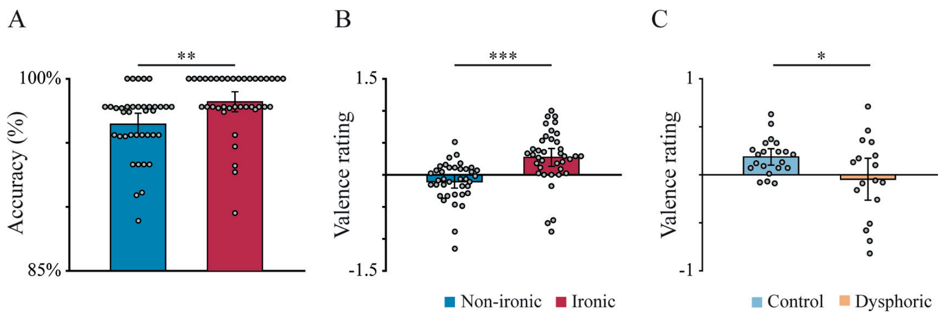

Fig. 2. Behavioral responses on the second day's measurement. (A) Mean accuracy of congruency detection and 95% confidence intervals to non-ironic (blue) and ironic (red) conversations. Values of individual responses are presented as a scatterplot. $^{**}p < 0.01$. (B) Mean values of valence ratings and 95% confidence intervals to non-ironic (blue) and ironic (red) conversations. Individual responses are presented as a scatterplot. $^{***}p < 0.001$. (C) Mean values of valence ratings and 95% confidence intervals in control (light blue) and dysphoric (light orange) groups (averaged over non-ironic and ironic). Individual responses are presented as a scatterplot. $^{*}p < 0.05$. The scale for valence ratings ranged from −2 (very unpleasant) to 2 (very funny), with 0 meaning neutral. Please note that the scale is different for B and C.

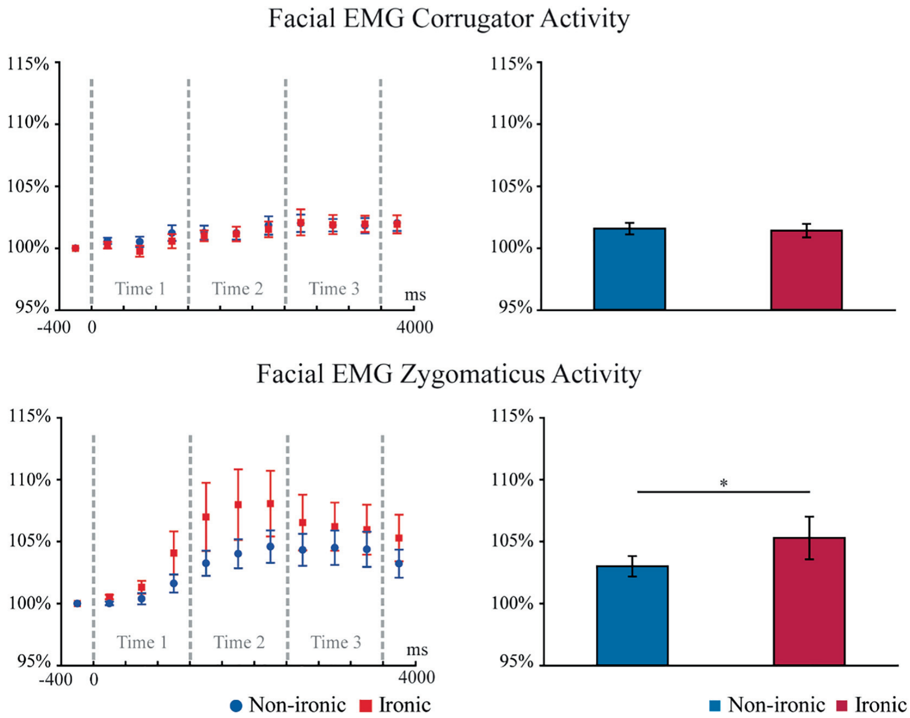

Fig. 3. The grand-averages of the mean EMG amplitude percentage relative to the baseline for the corrugator (upper) and for the zygomaticus (lower) to non-ironic (blue) and ironic (red) stimulus. Left: Average percentage values and standard error of mean (SE) are presented for descriptive purposes in 400-ms segments, and the grey dotted lines show the segments applied in the ANOVA (Time 1: 0–1200 ms; Time 2: 1200–2400 ms; Time 3: 2400–3600 ms). Right: The grand-averages of the mean values and SD for non-ironic and ironic responses averaged over the time segments reflect the main effect of Stimulus type (* $p < 0.05$) for the zygomaticus. The responses are averaged over the two groups, since there were no group differences (see Supplementary Fig. 3 for the responses in each group).

Table 2
Results of repeated measures ANOVAs for facial EMG corrugator and zygomaticus activity. F = F-values, df = degrees of freedom, p = p-values, η_p^2 = partial eta squared for effect size.

Facial EMG activity	Effect	F	df	p	η_p^2
Corrugator activity	Stimulus type (non-ironic vs. ironic)	0.863	1, 36	0.359	0.023
	Time window (1 vs. 2 vs. 3)	6.565	2, 72	0.009	0.154
	Group (control vs. dysphoric)	0.743	1, 36	0.394	0.020
	Stimulus type × Time window	1.142	2, 72	0.313	0.031
	Stimulus type × Group	0.427	1, 36	0.518	0.012
	Time window × Group	0.082	2, 72	0.922	0.002
	Stimulus type × Time window × Group	0.680	2, 72	0.510	0.019
Zygomaticus activity	Stimulus type (non-ironic vs. ironic)	4.579	1, 36	0.039	0.113
	Time window (1 vs. 2 vs. 3)	6.642	2, 72	0.002	0.156
	Group (control vs. dysphoric)	0.561	1, 36	0.459	0.015
	Stimulus type × Time window	2.436	2, 72	0.092	0.064
	Stimulus type × Group	0.347	1, 36	0.560	0.010
	Time window × Group	0.293	2, 72	0.747	0.008
	Stimulus type × Time window × Group	0.964	2, 72	0.386	0.026

was no significant difference between the activity in the period of 1200–2400 ms and 2400–3600 ms, $p = 0.674$. The main effect of Stimulus type was significant, $p = 0.039$. The facial EMG zygomaticus amplitude was larger after the ironic stimuli ($M = 105.3\%$, $SD = 0.105$) than after the non-ironic stimuli ($M = 103\%$, $SD = 0.051$). There were neither group differences nor interactions found in zygomaticus responses, all p-values > 0.091.

3.3. ERPs results

ERPs results are presented in Fig. 4 (N400-like activity) and Fig. 5 (P600). Grand-averaged responses showed larger responses for the ironic than the non-ironic stimuli at 300–500 ms and 500–800 ms after the onset of the keyword reflecting N400-like activity and P600, respectively. Results of repeated measures ANOVAs for N400-like activity and P600 activity are reported in Table 3.

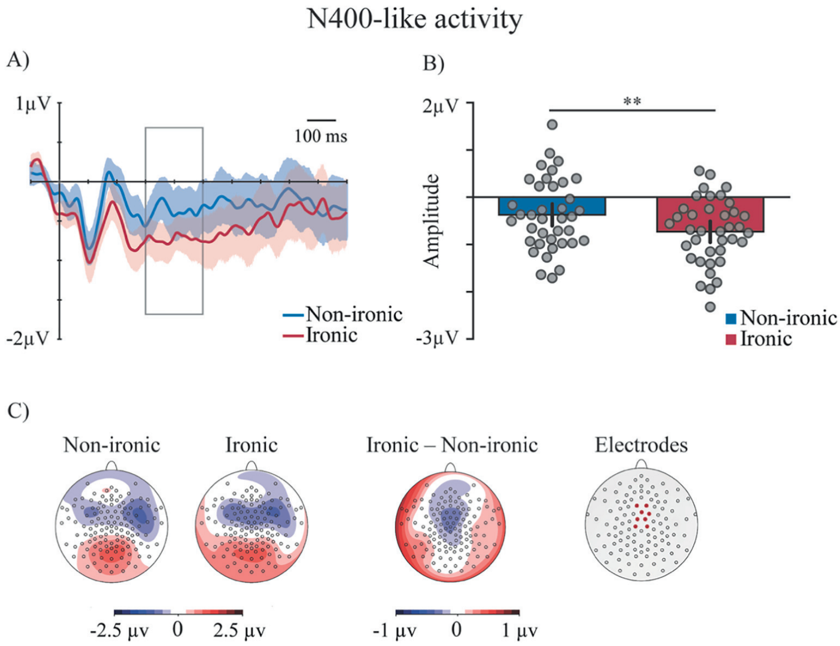

Fig. 4. Grand-averaged waveforms, mean amplitude values, topographical maps, and selections of electrodes for N400-like activity. A) Grand-averaged waveforms to non-ironic and ironic stimuli are presented. The blue and red shadows in the waveforms represent 95% confidence intervals. The grey rectangle shows the time window applied in the analysis for N400-like activity (mean amplitude values between 300 and 500 ms). B) Mean amplitudes for N400-like activity to non-ironic (blue) and ironic (red) stimulus are illustrated. The error bars represent 95% confidence intervals. $^{**}p < 0.01$, a main effect of Stimulus type. The scatterplots overlaid with the histograms represent individual participants' amplitudes in each condition. C) Grand-averaged topographical maps for non-ironic and ironic stimuli, and a difference between the two stimulus types in topographies and selections of electrodes (marked with red) for N400-like activity are shown. The responses are averaged over the two groups, since there were no group differences (see Supplementary Fig. 2 for the responses in each group).

3.3.1. N400-like activity

The analysis of N400-like activity revealed that the main effect of Stimulus type was significant, $p = 0.007$. The amplitude of the N400-like response was larger (toward negative polarity) for ironic (M = -0.73 μV, SD = 0.69) than non-ironic (M = -0.37 μV, SD = 0.75) stimuli. There were no other main or interaction effects, all p-values > 0.681.

3.3.2. P600

The ANOVA analysis of the P600 amplitude showed that the main effect of Stimulus type was significant, $p < 0.001$. Ironic conversations elicited larger amplitude toward positive polarity (M = 1.15 μV, SD = 0.83) than non-ironic conversations (M = 0.72 μV, SD = 0.62). There was also a three-way interaction effect of Stimulus type × ROI × Group, $p = 0.034$. No other main or interaction effects were observed, all p-values > 0.150.

Follow-up ANOVAs investigating the three-way interaction of Stimulus type × ROI × Group were conducted. The amplitude values for each ROI and each stimulus type in the control and the dysphoric groups for P600 are reported in Table 4.

First, follow-up two-way repeated measures ANOVAs with within-subjects variables Stimulus type (non-ironic vs. ironic) and ROI (left vs. right) were conducted separately for the control and the dysphoric group. In the control group, the analysis showed a significant main effect of Stimulus type, $F(1,20) = 5.771$, $p = 0.026, \eta_p^2 = 0.224$. The amplitude of the P600 response was larger for ironic (M = 1.13 μV, SD = 0.97) than non-ironic (M = 0.80 μV, SD = 0.65) stimuli. There were no other main or interaction effects in the control group, all p-values > 0.257. In the dysphoric group, a main effect of Stimulus type was observed, $F(1,16) = 22.864$, $p < 0.001, \eta_p^2 = 0.588$. The amplitude of the P600 response was larger for ironic (M = 1.17 μV, SD = 0.65) than non-ironic (M = 0.61 μV, SD = 0.57) stimuli. The main effect of ROI was not significant, $p > 0.297$. A marginally significant Stimulus type × ROI interaction effect, $F(1,16) = 3.912$, $p = 0.065, \eta_p^2 = 0.196$, was found in the dysphoric group. Paired t-tests revealed that, in the right ROI, P600 amplitude was larger to ironic than to non-ironic stimuli in the dysphoric group, $t(16) = 4.453$, $p < 0.001$, d = 0.832. In the left ROI, there was no significant difference between the responses to ironic and non-ironic stimuli, $p = 0.139$.

Second, follow-up two-way repeated measures ANOVAs with a within-subjects variable ROI (left vs. right) and a between-subjects variable Group (control vs. dysphoric) were conducted for the ironic and non-ironic stimuli separately. For the non-ironic stimuli, there were neither a main effect of ROI, a main effect of Group nor their interaction effect, all p-values > 0.340. For the ironic stimuli, the main effect of ROI and the main effect of Group were non-significant, both p-values > 0.776. There was a significant interaction effect of ROI × Group, $F(1,36) = 6.978$, $p = 0.012$, $\eta_p^2 = 0.162$, however. Post hoc tests based on independent samples t-tests comparing the groups in P600 amplitude to ironic stimuli separately at the left and at the right ROI indicated no group differences, both p-values > 0.135. Paired samples t-tests exploring the amplitude difference to ironic stimuli between the left and the right ROIs within each group were implemented. The analysis showed that the P600 amplitude to ironic stimuli was larger on the right ROI than on the left ROI in the dysphoric group, $t(16) = 2.399$, $p = 0.029$, d = 0.674, but there was no difference in the control group, $p = 0.132$.

For exploratory purposes, the measures of cognitive skills, which could be relevant on the cognitive aspect of irony processing, were applied in the ANCOVA of P600 responses. Values of three factors of the cognitive tests (executive function, list memory, semantic processing) were added as covariates independently in the ANCOVA model for P600 responses. Only list memory as a covariate in the ANCOVA changed the original results: the three-way interaction of Stimulus type × ROI × Group was not anymore significant, $p = 0.091$.

3.4. Correlations

There were no correlations between ERPs (the N400-like activity and the P600) and behavioral accuracy of congruency detection for either ironic or non-ironic stimulus condition, all p-values > 0.198. The correlations between facial EMG (corrugator and zygomaticus activity) and valence ratings of conversations in response to ironic and non-ironic stimulus condition were not found either, all p-values > 0.101.

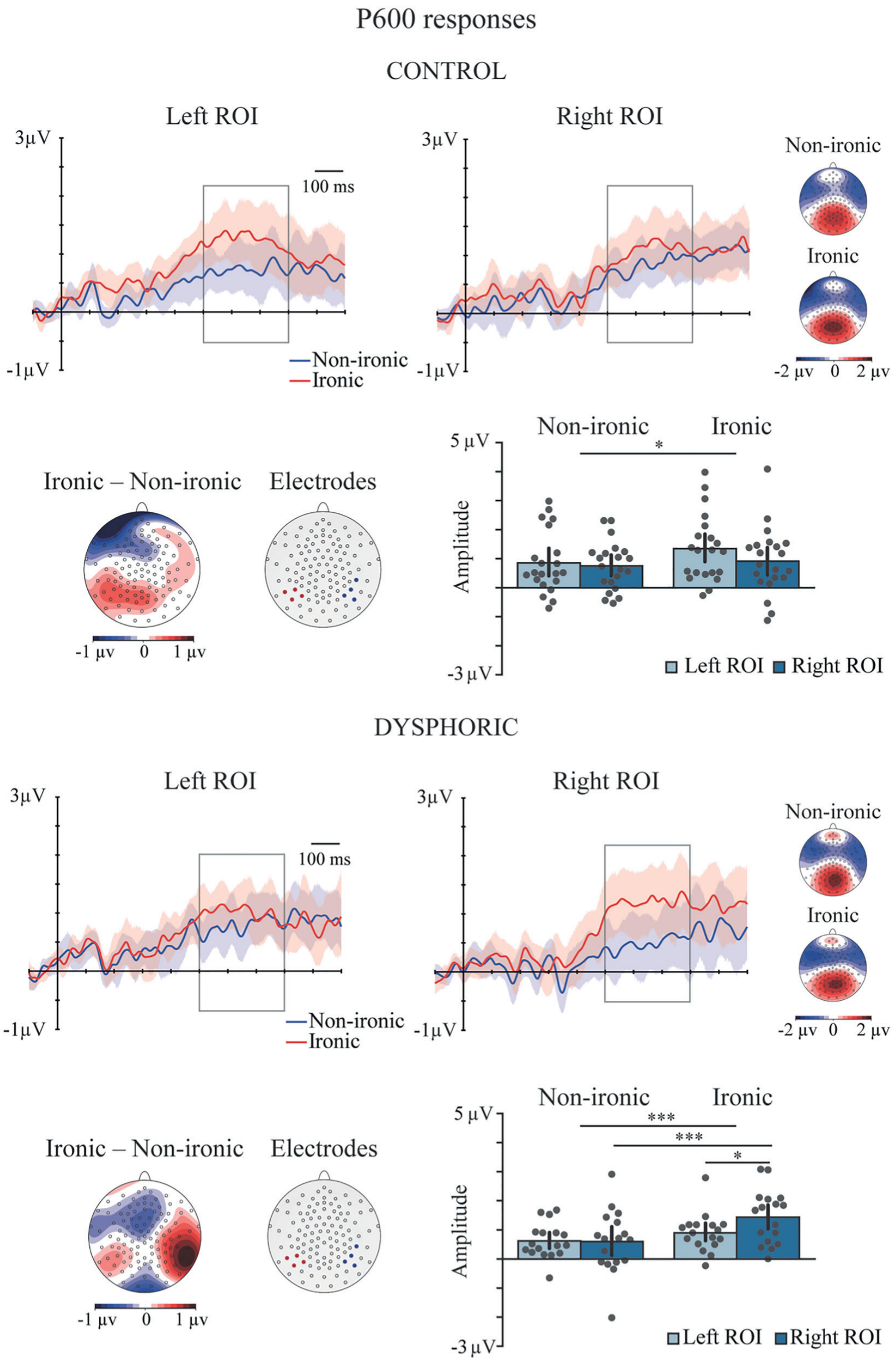

Fig. 5. Grand-averaged ERP waveforms, mean amplitude values, topographical maps, and selections of electrodes for P600 on left and right ROIs separately for the control and the dysphoric group. The blue and red shadows in the waveforms represent 95% confidence intervals. The grey rectangles in waveform figures show the time window applied in the analysis for P600 (mean amplitude values between 500 and 800 ms). The red dots and the blue dots represent the electrode cluster on the left and right ROI, respectively. The histograms represent mean amplitudes of P600 to non-ironic and ironic stimulus on the left and right ROIs. The error bars represent 95% confidence intervals (* $p < 0.05$; *** $p < 0.001$, post hoc paired t-tests investigating Stimulus type × ROI × Group interaction). The scatterplots overlaid with the histograms represent individual participants' amplitudes in each condition.

Table 3
Results of repeated measures ANOVAs for amplitudes of the N400-like activity and P600. F = F-values, df = degrees of freedom, p = p-values, η_p^2 = partial eta squared for effect size.

ERP	Effect	F	df	p	η_p^2
N400	Stimulus type (non-ironic vs. ironic)	8.279	1, 36	0.007	0.187
	Group (control vs. dysphoric)	0.170	1, 36	0.682	0.005
	Stimulus type × Group	0.077	1, 36	0.783	0.002
P600	Stimulus type (non-ironic vs. ironic)	23.243	1, 36	< 0.001	0.392
	ROI (left vs. right)	0.001	1, 36	0.973	< 0.001
	Group (control vs. dysphoric)	0.118	1, 36	0.734	0.003
	Stimulus type × ROI	0.337	1, 36	0.565	0.009
	Stimulus type × Group	1.656	1, 36	0.206	0.044
	ROI × Group	2.157	1, 36	0.151	0.057
	Stimulus type × ROI × Group	4.844	1, 36	0.034	0.119

Table 4
Mean amplitude values (μV) for P600 response for each ROI and each stimulus type in the control and dysphoric groups. SD = standard deviation.

Group	Stimulus type	Group	Mean (SD)
Control	Non-ironic	Left	0.86 (1.07)
		Right	0.75 (0.84)
	Ironic	Left	1.34 (1.16)
		Right	0.91 (1.16)
Dysphoria	Non-ironic	Left	0.62 (0.61)
		Right	0.60 (1.09)
	Ironic	Left	0.90 (0.66)
		Right	1.44 (0.92)

4. Discussion

We investigated irony comprehension and emotional reactions related to irony by measuring behavioral responses, facial EMG, and ERPs. The effect of depressiveness was investigated by comparing responses between the dysphoric group and the non-dysphoric control group.

The results showed that the participants in both groups found the ironic conversations to be funnier than the non-ironic conversations. However, overall, the dysphoric group rated both types of conversations as being less funny than the control group. Facial EMG activity in the zygomaticus major, which is an indication of smiling, was also greater in response to the ironic stimuli than the non-ironic stimuli in both groups. As expected, irony processing was reflected in the ERPs as enlarged amplitudes of the N400-like activity and the P600, indexing cognitive processing of irony. A difference in the P600 responses was found between the dysphoric group and the control group. Next, the results are discussed in details.

Behavioral responses indicated that the accuracy in the congruence detections was slightly better for the ironic stimuli than for the non-ironic stimuli for both groups, and the response time was descriptively longer, although the latter effect was not statistically significant. The descriptively longer response time may reflect higher cognitive effort and cognitive complexity in processing ironic stimuli. Consistent with previous studies that found no difference in the detection of semantic violations between the depressed and control participants (Deldin et al., 2006; Klumpp et al., 2010), we found no differences in the accuracy of the congruence detection between the dysphoric and control groups. Moreover, no difference in response time was found between the two groups.

Both groups rated the ironic conversations funnier than the non-ironic ones, which is compatible with the findings reported in previous studies that compared the ratings of ironic and literal sentences (Calmus and Caillies, 2014; for ironic criticism see, Dews et al., 1995) and the degree of perceived humor in ironic and literal stories in healthy participants (Akimoto et al., 2014). In comparing the two groups, the dysphoric group's valence ratings (unpleasant vs. funny) were lower than the control group's for both ironic and non-ironic stimuli. This finding is in line with previous studies that reported lower reactivity to different kinds of emotional stimuli in depression (Bylsma et al., 2008; Moran et al., 2012; Rottenberg et al., 2005). Notably, the difference in valence ratings between the two groups may not be explained by differences in the groups' preference of humor styles, because the groups did not differ in any of the measured humor styles (for the results on humor style, see the Supplementary materials).

Consistent with the valence ratings, the activity of the zygomaticus muscle, which is known to indicate smiling (Van Boxtel, 2010), showed a relatively larger response to the ironic stimuli than to the non-ironic stimuli. This most probably indicated positive emotions related to irony at the whole sample level. A previous study using the facial EMG method have also demonstrated positive emotions to ironic criticism (Thompson et al., 2016).

There were no differences in the facial EMG responses between the dysphoric group and the control group. This finding was surprising, taking into account the well-documented alterations in emotional information processing in depression (e.g., Gotlib and Joormann, 2010; Leppänen, 2006) and the reduced tendency to react with exhilaration to funny stimuli (Uekermann et al., 2008; Falkenberg et al., 2011). It is possible that the two groups did not differ in their facial EMG responses because similar to the dysphoric group, the ironic stimuli were not found to be very funny in the control group, although they were found to be relatively more funny than the non-ironic conversations at the whole sample level. Another possible reason for the lack of group difference could be the large variance we observed especially in the valence ratings and zygomaticus facial EMG for the dysphoric group. The variance can be expected within dysphoric participants due to the heterogeneity of depression related to different symptom profiles (e.g., more or less vegetative vs. affective symptoms), differences in amount of symptoms or diagnosis type (e.g. atypical depression vs. melancholic depression).

Regarding the ERP data, modulation of both the N400-like activity and P600 related to irony were observed. This finding is compatible with the traditional standard pragmatic view of irony comprehension (e.g., Grice, 1975), which states that, for irony comprehension, detecting and distinguishing the incongruence in a semantic context (reflected by the N400-like activity) and inferring and interpreting the speakers' implied meaning (reflected by the P600) are required to understand ironic statements. Because we did not evaluate the participants' familiarity with the words in the commenting sentences, our study was unable to test the graded salience hypothesis (e.g., Giora and Fein, 1999; Giora, 2003). However, since modulation of both the N400-like activity and P600 in response to irony was found, our results support the two-stage model of irony processing (Giora, 2003; Grice, 1975) rather than the one-stage model (the direct access view, e.g., Gibbs, 2002).

The N400-like activity was more negative in polarity in response to the ironic stimuli than in response to the non-ironic stimuli. Unlike traditional N400 (e.g., Kutas and Federmeier, 2011), the response did not seem to have a clear peak (see also, Filik et al., 2014) and was slightly frontally-distributed. Here, we applied naturally spoken sentences in which the position of the keyword varied between the sentences. This may have affected the morphology and the topography of the N400 response (Kutas and Federmeier, 2011), which is usually measured in a condition where the keyword is in the end of the sentence (e.g., Filik et al., 2014; Regel et al., 2011, 2014).

The observed N400-like activity to irony is in line with previous findings of N400 elicited to irony (Cornejol et al., 2007; Filik et al., 2014; Caillies et al., 2019), humor (Coulson and Kutas, 2001; Coulson and Wu, 2005), and other nonliteral language (metaphor: Coulson and Van Petten, 2002) in showing enhanced response amplitude to nonliteral stimuli (here ironic) in comparison to literal stimuli (here non-ironic). This finding may suggest that the participants had difficulty processing the meaning of the commenting sentence in the context of the opposing contextual picture. This difficulty may stem from the holistic strategy the participants applied during comprehension (Cornejol et al., 2007) or the stimuli, which were unfamiliar to the participants, because a previous study only found N400-like modulation for unfamiliar ironic utterances (Filik et al., 2014). Some studies have not found N400 modulation for irony, however (Balconi and Amenta, 2008; Regel et al., 2011, 2014). Regel et al. (2011, 2014) reported that the lack of N400 modulation to ironic stimuli means that the participants were capable of comprehending irony based on the supportive context, with no difficulty in semantic interpretation. In our study, even though we did not measure the difficulty of semantic interpretation directly with behavioral tests, the results of congruence detection showed that the participants were very accurate in categorizing both congruent (i.e., non-ironic) and incongruent (i.e., ironic) picture-sentence pairs, and we found the amplitude of the N400 was still modulated by the irony. However, the results regarding the N400 effect should be interpreted with caution, because the effect size of the irony effect is small and as mentioned earlier, it is different in morphology from traditional N400 effects.

There was no difference in the N400-like activity in response to ironic stimuli between the dysphoric and control groups. This result suggests that semantic processing related to irony is not altered in dysphoria. This finding is consistent with previous results showing that patients with mood disorders have normal semantic processing in a passive sentence-viewing task, as indexed by N400 (Deldin et al., 2006).

As expected, P600, which displayed a centro-parietal distribution, was also modulated by irony in our study. The amplitude of P600 was more positive for the ironic punchlines than the non-ironic punchlines; this result has also been reported in previous studies on irony comprehension (Baptista et al., 2018; Filik et al., 2014; Regel et al., 2011, 2014; Caillies et al., 2019). Visual observation of the grand-averaged difference topographies (ironic minus non-ironic) for the P600 responses in Filik et al. (2014) and those in the healthy controls in our study shows a remarkable similarity: they both show irony-related activity in the central and in the left parietal electrode sites. Moreover, the results in our study and in previous studies are similar in that no differences were found in irony modulation between the left and right ROIs in the healthy controls (Filik et al., 2014; Regel et al., 2011, 2014).

In the present study, we defined the EEG-electrode sites for the analysis based on a data-driven method, and we found two ROIs for the P600 modulation: one in the left parietal electrode cluster and the other in the right parietal electrode cluster. Previous ERP studies investigating irony comprehension have selected the electrodes for the analysis either based on previous literature (Caillies et al., 2019) or have applied several fixed ROIs for statistical analysis (Filik et al., 2014; Regel et al., 2011, 2014). The studies that had many different fixed ROIs in analysis (i.e., anterior vs. posterior vs. central vs. left vs. right ROIs) have found maximum irony-related P600 activity over the posterior electrode sites (left mastoid reference: Regel et al., 2011; average reference: Filik et al., 2014) or over the right central and the left and right parietal electrode sites (left mastoid reference: Regel et al., 2014). Thus, it seems to be that in the present study, in which a data-driven method was used to select the electrode sites, we found the irony modulation at approximately same area as those of studies that used fixed ROIs (Filik et al., 2014; Regel et al., 2011).

Here, the participants did not engage in any task related to the stimuli during the EEG/EMG-measurement, and the behavioral evaluations were conducted on separate days. Therefore, it is unlikely that the present study's finding of enhanced P600 in relation to irony is elicited by the requirements of the comprehension tasks or categorization tasks, which were possible reasons for the P600 modulation in studies by Regel et al. (2011) and Filik et al. (2014), respectively. Regel et al. (2011) also suggested that an increased P600 amplitude to irony may reflect the processing of emotional information expressed by ironic utterances. Partly supporting this idea, a recent study found that greater P600 modulation was observed in relation to ironic criticism than ironic praise (Caillies et al., 2019). In the present study, we had positive keywords in half of the sentences and negative keywords in another half of the sentences. Due to the limited number of trials in each sub-type (ironic criticism or ironic praise), we were unable to analyze the possible effects related to the different sub-types. However, we found no correlations between the amplitude of P600 and valence ratings of the stimuli. Thus, it seems an unlikely explanation that, in the present study, the modulation of P600 is due to the processing of emotional information. Consequently, we considered that the larger amplitude of P600 likely reflects the greater inferential effort required for the resolution of the ironic punchlines than for the non-ironic punchlines arising from the conflict between the meaning of the keyword and the contextual picture in the irony trials.

A difference in P600 was also found between the dysphoric and control groups. In the dysphoric group, irony modulated the amplitude more in the right ROI than the left ROI; in the control group, irony modulation was found equally in both ROIs. Underlying cause of the different hemispheric balance between the dysphoric and control groups and its functional significance is unknown and needs further investigations. However, Kalatzis et al. (2004) applied a machine learning technique to classify the control and depressed individuals based on P600 responses to numbers during a working memory test, and they found that the discrimination accuracy to distinguish depressed individuals from controls was higher using the electrodes at the right hemisphere in comparison to the electrodes at the left hemisphere. The authors suggested that this result could be related to a right hemispheric dysfunction in depression (Kalatzis et al., 2004), but this assumption requires further investigations.

In addition to the analysis investigating group differences categorically, we also calculated simple linear regressions for P600 (separately for the left and right ROI), facial EMG activities, and valence ratings with BDI-II scores as a predictor. However, the regression analyses did not show any significant effects (see Supplementary materials). One reason for this result could be that self-assessment questionnaires, such as the BDI-II, are not the most accurate measures of depressive symptoms because some depressed individuals do not have a clear awareness of their symptoms; thus, they can inaccurately estimate their symptoms, which in turn can lead to non-significant linear regressions between amount of symptoms and responses to irony.

In the present study, the cognitive test results showed that there were no differences between the dysphoric and control groups in terms of memory, executive functions, or semantic processing (see Supplementary materials). This indicates that, in our sample, cognitive abilities were well-preserved in the dysphoric group. It is possible that the ERPs that reflect the cognitive aspect of irony processing (N400-like activity and P600) could better show depression-related alterations in a sample where alterations in cognition exist. In previous studies, cognitive dysfunction has been mostly associated with recurrent depression (e.g., Fossati et al., 2004; Talarowska et al., 2015). In our sample, the dysphoric participants were young adults, and only one participant reported being diagnosed with recurrent depression. When applying values of the factor list memory as a covariate in the analysis of covariance (ANCOVA), the original results were changed for P600: the three-way interaction of Stimulus type × ROI × Group was no longer observed. This suggests that the difference between the groups is, at least to some extent, driven by differences in memory functions. However, this interpretation needs to be considered cautiously because there were no interactions between the factor list memory and the other variables, and there was no group difference in the list memory.

Several limitations in the present study are worth noting. The dysphoric participants self-reported their diagnostic status; not all of them had been recently diagnosed with depression. However, BDI-II scores were used to measure the depressive symptoms at the time of the measurement, and all the participants in the dysphoric group had scores of 14 or more, reflecting at least mild depression (Beck et al., 1996). Still, our results may not be generalized to clinical depression. Moreover, there were more female participants than male participants in both the dysphoric and the control groups. Therefore, our results cannot unconditionally be generalized to both genders. However, the proportion of gender distribution in the dysphoric and control groups was similar. Furthermore, ten dysphoric participants were taking antidepressant medication while participating in the study, but analyses using the medication status as a covariate did not reveal any interactions between the medication status and the dependent variables. It is also notable that our stimuli included both ironic praise and ironic criticism, and as mentioned before, we were not able to analyze the effects separately for each sub-type. It is possible that valence ratings could have been more positive, at least in the control group, if only ironic criticism had been used (Dews et al., 1995; Thompson et al., 2016), and this could have led to group differences also in facial EMG responses. Last, the ERP analysis was based on sensor-level analysis, and we did not utilize any source localization methods. Therefore, we cannot accurately estimate the sources of the activity in the two groups. Future studies should confirm our findings with a larger sample, and also investigate the sources of the brain activity related to irony comprehension.

One advantage of the present study is its design in which the non-ironic and ironic conditions were defined by the previous contextual picture, which provided either a non-ironic or ironic context for the commenting sentence. This arrangement allows for a valid comparison of the non-ironic and ironic conversations irrespective of the low-level stimulus features, the position of the keywords, or other potentially confounding factors because the comparison was always made between sentences that were physically identical. A definite strength of this study is also its use of multimodal recordings and two measurement sessions conducted on separate days. Namely, the ratings of congruency recognition were collected separately after the EEG and EMG measurements. This allowed the participants to focus on the stimuli during the EEG/EMG recordings without responding.

5. Conclusions

To summarize, facial EMG activity in the zygomaticus major was greater after ironic stimuli than after non-ironic stimuli, which corresponds to the behavioral evaluations in which the participants rated the ironic conversations funnier than the non-ironic ones. Thus, the conversational irony applied in our study seemed to evoke positive emotions. However, the valence ratings for all the stimuli were generally lower in the dysphoric group than in the control group, probably reflecting blunted emotional reactivity in dysphoria. The amplitudes of the irony-related ERPs, N400-like activity and P600, were greater for the ironic stimuli than the non-ironic stimuli, reflecting difficulties in integrating the irony-related keyword to the context and the cognitive effort required to interpret the ironic meaning, respectively. P600 had a different hemispheric balance in the dysphoric group and the control group; while the irony-related activity was larger in the right ROI than left ROI in the dysphoric group, no such difference in lateralization was evident in the control group. More research is needed to confirm this finding and to define the cortical sources of the activity related to irony comprehension in healthy and depressed brains.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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SUPPLEMENTARY MATERIALS

1 Humor Styles Questionnaire

Humor Styles Questionnaire (HSQ; Martin et al., 2003) was filled out on the same day with the second day's behavioral measurement. The HSQ, translated into Finnish based on the original version, consists of a 32-item measure with a Likert-scale from 1 to 7 (totally disagree = 1, totally agree = 7). The HSQ evaluates individual preference for the use of humor in four dimensions (affiliative, self-enhancing, aggressive, self-defeating) and has been applied in previous studies to investigate the relationship between the use of humor styles and depressive symptoms, loneliness, or suicidal ideation (e.g., Frewen et al., 2008; Schermer et al., 2017; Tucker et al., 2013). Here, HSQ was applied to explore if there were differences in humor style preference between the dysphoric and control groups, which could explain possible group differences in the responsiveness to irony, since irony is related to sarcasm (Kreuz and Glucksberg, 1989) that can be categorized as aggressive humor (Martin et al., 2003).

1.1 Analysis and statistics for the Humor Style Questionnaire and behavioral data

The reliability of the HSQ was first estimated based on internal consistency values. Cronbach's alphas for each dimension were: affiliative humor = .853; self-enhancing = .829; aggressive humor = .684; self-defeating = .756. The averaged HSQ scores were calculated separately for each participant and dimension. For the HSQ scores, multivariate analysis of variance (MANOVA) was applied with a within-subject factor Humor style (affiliative, self-enhancing, aggressive, self-defeating) and a between-subject factor Group (control, dysphoric). An additional MANOVA analysis, similar to the previously mentioned but with current medication status (whether the participant currently had depression medication or not) serving as a covariate, was conducted. Post-hoc tests for within-subject comparisons were implemented by applying repeated measures of analysis of variance (ANOVAs) with Bonferroni correction in the control and dysphoric groups separately. Post-hoc tests comparing each humor style dimension between the control and dysphoric groups were performed by using two-tailed independent samples *t*-tests with Bootstrap statistics based on 1000 permutations as implemented in IBM SPSS Statistics 24.0 (Armonk, NY: IBM corporated). *P*-values in multiple comparisons for independent sample *t*-tests were adjusted by false discovery rate (Benjamini and Hochberg, 1995).

Pearson's correlation coefficients (two-tailed) were used to evaluate the relationship between depressive symptoms (BDI-II scores) and humor styles. Multiple correlations were controlled by applying false discovery rate (Benjamini and Yekutieli, 2001) at 0.05.

1.2 Results for Humor Style Questionnaire

The MANOVA indicated no main effect of Group (p = .929). A main effect of Humor style was found, $F(3,34) = 63.356$, $p < .001$, $\eta_p^2 = .848$. The main effect was modified by an interaction effect of Humor style × Group, $F(3,34) = 3.827$, $p = .018$, $\eta_p^2 = .252$. MANOVA with current medication status as a covariate variable showed no Stimulus condition × Current medication status interaction, p = .587.

Separate ANOVAs for the two groups showed a significant main effect of Humor style in each group (dysphoric: $F(3,48) = 22.616$, $p < .001$, $\eta_p^2 = .586$; control: $F(3,60) = 47.029$, $p < .001$, $\eta_p^2 = .702$). For the dysphoric group, pairwise comparisons with Bonferroni correction showed that the tendency to use an affiliative humor style in the dysphoric participants was greater compared with the tendency to use a self-enhancing, an aggressive, or a self-defeating humor style, all *p*-values < .001. The comparisons also showed that the dysphoric participants were more likely to use a self-defeating humor style than an aggressive humor style, $p = .005$. There were no differences between using a self-enhancing humor style and an aggressive or a self-defeating humor style. Among the controls, pairwise comparisons with Bonferroni correction showed that the control group had the greatest preference for an affiliative humor style compared with a self-enhancing ($p = .009$), an aggressive ($p < .001$), or a self-defeating ($p < .001$) humor style. Furthermore, the control group were most unlikely to use an aggressive humor style compared with an affiliative, a self-enhancing ($p < .001$), or a self-defeating ($p = .005$) humor style. The pairwise comparisons also revealed that the control participants prefer to use a self-enhancing humor style rather than a self-defeating humor style, $p = .003$. Results of post-hoc tests comparing each humor style dimension between the control and dysphoric groups are shown in Supplementary Table 3. Mean values, standard deviation (SD) and range of Humor Style Questionnaire (HSQ) scores separately for each humor style dimension and group are also presented in Supplementary Table 3.

No correlations were found between the amount of depressive symptoms (measured with the BDI-II scores) and scores for each HSQ dimension when the whole sample was included or when only the dysphoric group was included in the analysis (all *p*-values > .100).

2 Linear regression analyses

In addition to the ANOVAs reported in the main text, simple linear regression analyses were conducted for the whole sample to investigate the relationship between the amount of depressive symptoms (BDI-II scores) and ERP responses (P600 only, because we hypothesized a group difference specifically for it), facial EMG amplitudes and behavioral evaluations (group difference hypothesized for valence ratings of conversation) separately. BDI-II scores were applied as a predictor of P600 amplitude, facial EMG amplitude and behavioral ratings for valence. Results of simple linear regression model with BDI-II scores as a predictor are presented in Supplementary Table 4.

In summary, the results of simple linear regression analyses showed that there were no significant relationships between BDI-II scores and P600 amplitudes, or facial EMG amplitudes, or behavioral valence ratings.

3 Cognitive tests

3.1 Principal component analysis on cognitive tests

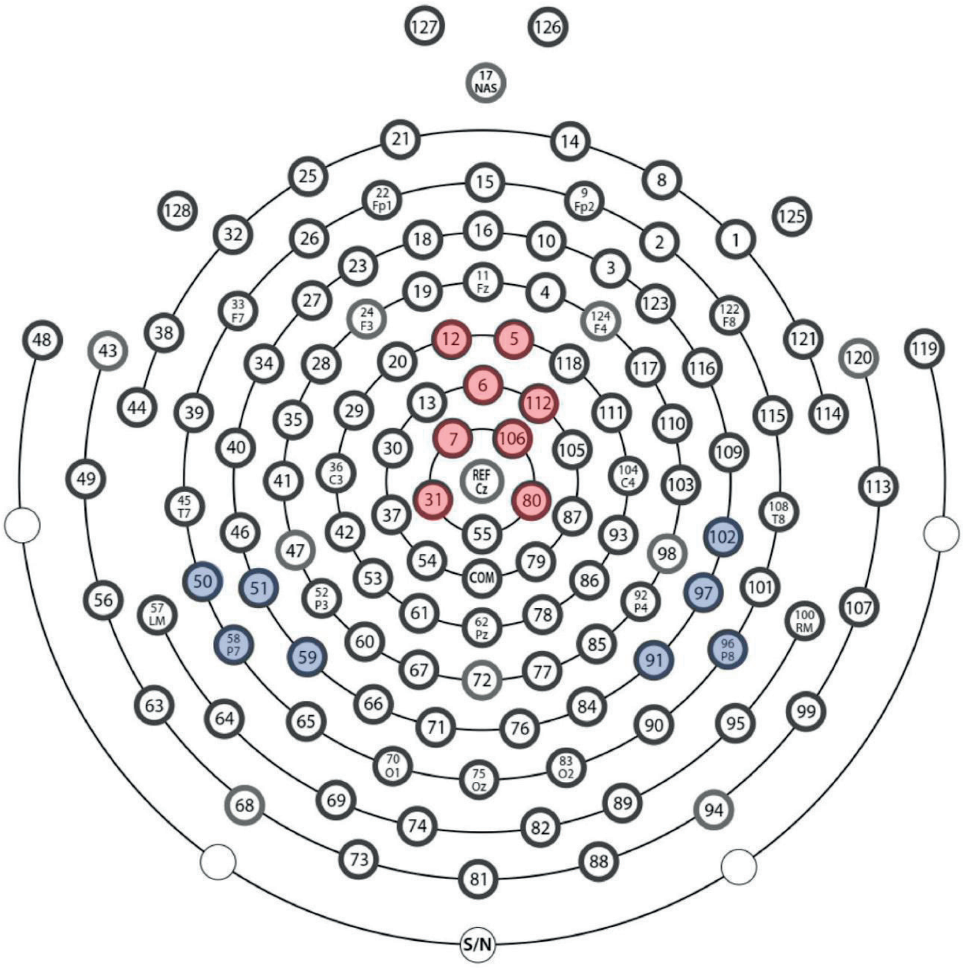
In order to reduce variables for analysis of covariance investigating effect of cognitive abilities for P600 responses, principal component analysis (PCA) using an Oblimin rotation with Kaiser Normalization was conducted to extract factors of the cognitive tests. First, we selected the cognitive tests that can be expected to associate with irony processing or the cognitive deficits in depression (Supplementary Table 5). Thus, eight tests were applied as variables in the PCA to investigate factor solutions. With a criteria of eigenvalue larger than 1.0, the PCA showed that three factors which could explain 71.5% of the variance, were extracted (Supplementary Table 5). Finally, these three factors, named executive function, list memory, and semantic processing, were utilized as covariates independently in ANCOVA models of P600. In addition, a two-way repeated measures ANOVA with a within-subject variable Cognitive factor (executive function vs. list memory vs. semantic processing) and a between-subject variable Group (control vs. dysphoric) was conducted to examine possible group difference in cognitive factors.

3.2 Results of group comparison in cognitive factors

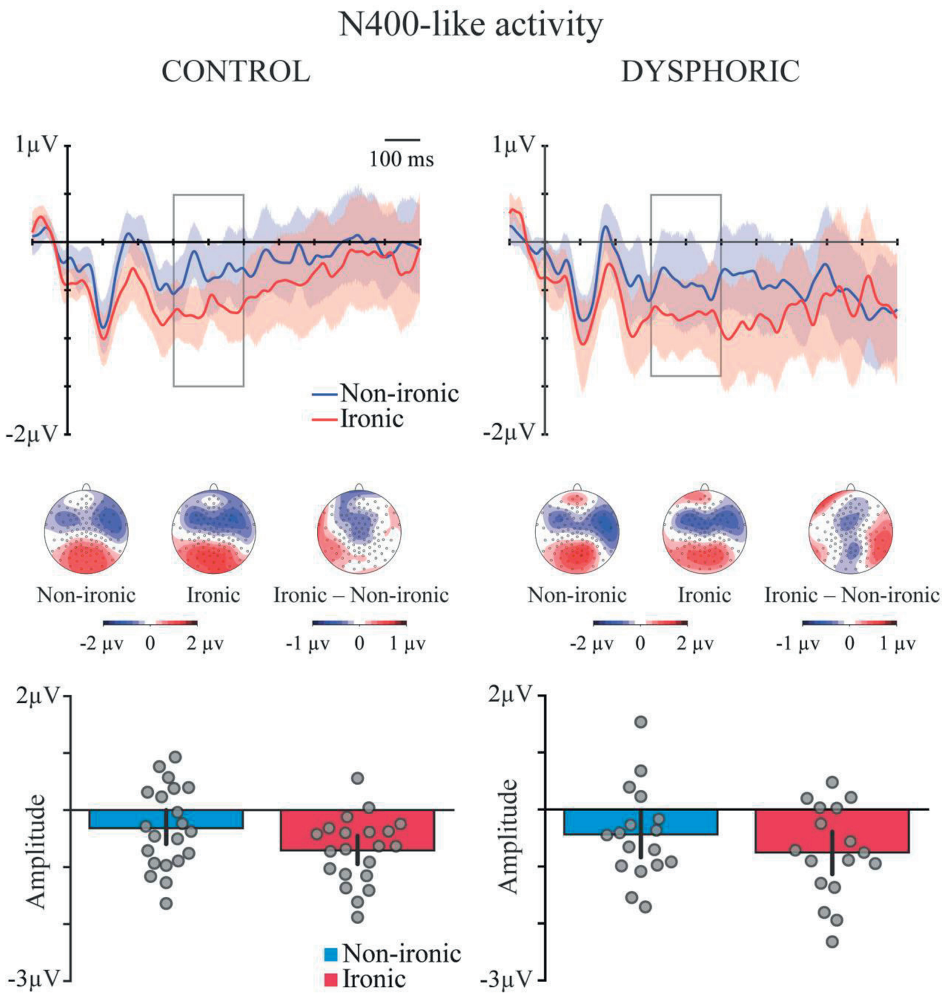
The two-way repeated measures ANOVA showed that there was neither main effect of Cognitive factor ($F(2, 72) = 0.015$, $p = .985$, $\eta_p^2 < .001$) nor main effect of Group ($F(1, 36) = 0.917$, $p = .345$, $\eta_p^2 = .025$). The interaction of Cognitive factor and Group were non-significant, $F(2, 72) = 1.368$, $p = .261$, $\eta_p^2 = .037$.

4 Permutation tests for electrode selection

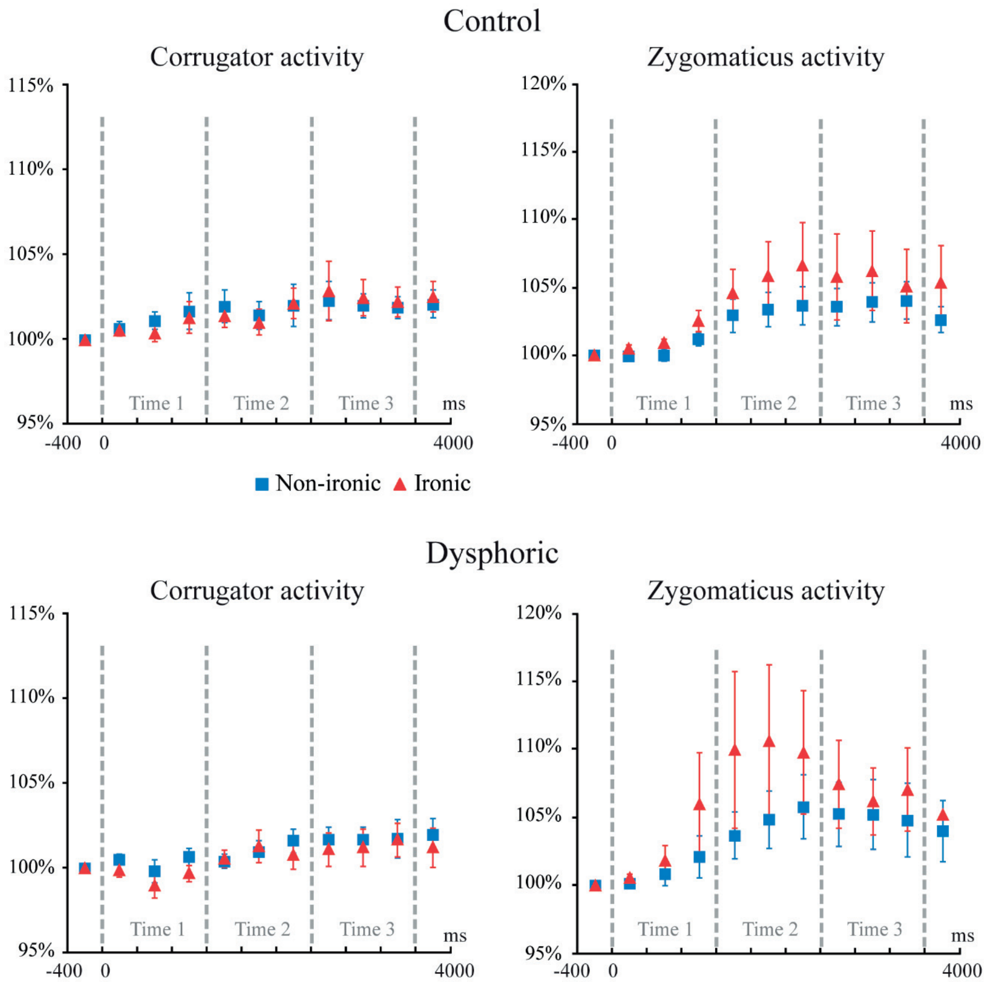
For the N400-like activity and P600, the selection of the electrodes for the further statistical analyses was based on a data-driven method (see also, e.g., Hämäläinen et al., 2018; Strömmer et al., 2017). BESA Statistics 2.0 software (BESA GmbH, Graefelfing, Germany) was applied to perform cluster-based permutation tests (Maris and Oostenveld, 2007) between the amplitude values of responses to ironic and non-ironic trials with 3000 iterations. In order to enhance the sensitivity of the test (Groppe, Urbach, and Kutas, 2011; Maris and Oostenveld, 2007), time points where stimulus type effect (non-ironic vs. ironic) related N400-like activity and P600 is unlikely to be observed were excluded. That is, we performed the permutation tests including each time point from two separate time windows: 300 to 500 ms after stimulus onset for the N400-like activity (Kutas & Federmeier, 2011), and 500 to 800 ms after stimulus onset for P600 (Bornkessel-Schlesewsky & Schlesewsky, 2008). For both tests, the channel (electrode) cluster distance was set to 3.5 cm, and the alpha level for significant cluster was 0.05. In time window of 300-500 ms (N400-like activity), the cluster-based test showed one electrode cluster (p = .025), where the responses to ironic and non-ironic sentences differed. In time window of 500-800 ms (P600), two clusters were observed: one on the left (p = .013) and one on the right (p = .014) hemisphere. Then, we located the highest t-value (t-valuemax) within each electrode cluster: in the electrode cluster for N400-like activity: t-valuemax = 4.0; in the electrode clusters for P600, for the left cluster: t-valuemax = 4.5, and for the right cluster: t-valuemax = 4.0. The electrode with the highest t-value and its surrounding electrodes within the cluster were selected to the further analyses if the highest t-value of the electrode was larger than the 75% of t-valuemax (for N400-like activity: the highest t-values for all selected electrodes > 3.0; for P600: the highest t-values for selected electrodes on the left > 3.4, for selected electrodes on the right > 3.0). The electrodes applied in the statistical analysis, i.e., the results of this procedure, are depicted in Supplementary Figure 1.



Supplementary Figure 1. Map of EGI 128-Channel Net (HydroCel Geodesic Sensor Net) and the electrodes applied in the analyses. For N400-like activity, electrodes 5, 6, 7, 12, 31, 80, 106, 112 (red fillings) were applied in the analyses. For P600, electrodes 50, 51, 58, 59, 91, 96, 97, 102 (blue fillings) were applied in the analyses.



Supplementary Figure 2. Grand-averaged waveforms, topographical maps and histograms depicting mean amplitudes for N400-like activity to non-ironic and ironic stimuli in control (left) and dysphoric (right) group. Please refer to Supplementary Figure 1 for the electrode sites applied in the waveforms and histograms (averaged activity of the electrodes within the ROI presented here). In the waveform figure, the blue and red shadows represent 95% confidence intervals, and the grey rectangles the time window applied in the analysis for N400-like activity (mean amplitude values between 300–500 ms). The histograms shows the mean amplitudes in the analysis window and the error bars represent 95% confidence intervals. The scatterplots represent individual participants' amplitudes.



Supplementary Figure 3. The grand-averages of the mean EMG amplitude percentage relative to the baseline for the corrugator (left) and for the zygomaticus (right) to non-ironic (blue) and ironic (red) stimulus in control and dysphoric group. Average percentage values and standard error of mean (SE) are presented for descriptive purposes in 400-ms segments, and the grey dotted lines show the segments applied in the ANOVA (Time 1: 0–1200 ms; Time 2: 1200–2400 ms; Time 3: 2400–3600 ms).

Supplementary Table 1. Cognitive test scores in the control and dysphoric group. The statistics show the results based on two-tailed independent samples t-tests comparing the groups in the scores.

Cognitive test	Mean ± Standard deviation		Mean difference	*p*[a]	*d*
	Control (n = 21)	Dysphoric (n = 17)			
AVLT immediate (#)	13.33 ± 2.03	12.00 ± 2.72	1.33	.092	0.554
AVLT delayed (#)	13.10 ± 1.92	11.94 ± 2.11	1.15	.086	0.576
Digit span (p)	9.81 ± 1.60	10.41 ± 2.65	0.60	.418	0.183
Digit-letter (p)	12.57 ± 2.58	10.94 ± 3.34	1.63	.098	0.546
Logical memory immediate (p)	29.05 ± 5.39	29.71 ± 9.35	0.66	.799	0.143
Logical memory delayed (p)	27.81 ± 5.75	27.47 ± 9.04	0.89	.339	0.271
Symbol search (p)	12.52 ± 3.40	13.59 ± 3.47	1.06	.348	0.311
Digit symbol (p)	13.05 ± 2.38	13.59 ± 2.90	0.54	.531	0.204
TMT-A (s)	25.90 ± 8.78	25.53 ± 8.24	0.37	.894	0.044
TMT-B (s)	55.32 ± 23.71	55.38 ± 23.77	0.06	.994	0.003
Stroop1 reading (s)	47.16 ± 7.25	44.69 ± 6.37	2.46	.279	0.361
Stroop2 color labelling (s)	60.43 ± 9.81	62.35 ± 13.69	1.92	.618	0.161
Stroop3 inhibition (s)	87.37 ± 14.00	85.74 ± 17.76	1.63	.754	0.101
Similarities (p)	13.76 ± 2.14	13.12 ± 2.50	0.64	.398	0.275
Fluency phonemic (#)	23.93 ± 4.29	20.50 ± 3.93	3.45	.016 (0.256)	0.834
Fluency semantic (#)	32.05 ± 5.32	30.88 ± 5.01	1.17	.495	0.226

Note. Differences between two groups were tested by using two-tailed independent-samples t-tests. *d* = Cohen's *d*, AVLT = Auditory Verbal Learning Test, TMT = Trail Making Test, # = scores measured in the number of items, p = point, more means better, s = second, less means better.

[a]Uncorrected *p*-values. P-values smaller than .05 are in bold, and for them corrected *p*-values based on FDR (false discovery rate) are presented in parentheses.

Supplementary Table 2. List of cognitive tests applied and references to them.

Cognitive test (Version)	References
Memory	
Auditory Verbal Learning Test	Günther, T., Holtkamp, K., Jolles, J., Herpertz-Dahlmann, B., and Konrad, K. (2004). Verbal memory and aspects of attentional control in children and adolescents with anxiety disorders or depressive disorders. J. Affect. Disord. 82, 265–269. doi:10.1016/j.jad.2003.11.004.
Digit span (WAIS-III)	Ramsay, M. C., and Reynolds, C. R. (1995). Separate Digits tests: A brief history, a literature review, and a reexamination of the factor structure of the test of memory and learning (TOMAL). Neuropsychol. Rev. 5, 151–171. doi:10.1007/BF02214760.
Letter-number sequencing task (WMS-III)	Crowe, S. F. (2000). Does the Letter Number Sequencing task measure anything more than digit span? Assessment 7, 113–117. doi:10.1177/107319110000700202.
Logical memory task (WMS-R)	Elwood, R. W. (1991). The Wechsler Memory Scale-Revised: Psychometric characteristics and clinical application. Neuropsychol. Rev. 2, 179–201. doi:10.1007/BF01109053.
Processing speed	
Symbol search (WAIS-IV)	Wisdom, N. M., Mignogna, J., and Collins, R. L. (2012). Variability in wechsler adult intelligence scale-IV subtest performance across age. Arch. Clin. Neuropsychol. 27, 389–397. doi:10.1093/arclin/acs041.
Digit symbol substitution test/Coding (WAIS-IV)	
Executive function	
Trail Making Test A & Trail Making Test B	Bowie, C. R., and Harvey, P. D. (2006). Administration and interpretation of the Trail Making Test. Nat. Protoc. 1, 2277–2281. doi:10.1038/nprot.2006.390.
The Stroop Color-Word Test	Alvarez, J. A., and Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. Neuropsychol. Rev. 16, 17–42. doi:10.1007/s11065-006-9002-x.
Linguistic ability	
Similarities (WAIS-IV)	Davies, G., and Piovesana, A. (2015). Adult Verbal Abstract Reasoning Assessment Instruments and their Clinimetric Properties. Clin. Neuropsychol. 29, 1010–1033. doi:10.1080/13854046.2015.1119889.
Fluency phonemic & Fluency semantic (Verbal fluency tests)	Laine, M. (1988). Correlates of word fluency performance. In P. Koivuselka-Sallinen & L. Sarajarvi (Eds.), Studies in languages (Vol. 12). Joensuu, Finland: University of Joensuu.

Note. WMS-R = Wechsler Memory Scale-Revised, WMS-III = Wechsler Memory Scale-Third Edition, WAIS-III = Wechsler Adult Intelligence Scale-Third Edition, WAIS-IV = Wechsler Adult Intelligence Scale-Fourth Edition.

Supplementary Table 3. Mean values, standard deviation (SD) and range of Humor Style Questionnaire (HSQ) scores separately for each humor style dimension and group reflecting significant interaction of humor style × group. Statistics show post hoc tests (two-tailed independent samples *t*-tests, bootstrapping with 1000 permutations) comparing the humor style scores between the groups in each dimension.

HSQ		Control	Dysphoric	Statistics
Affiliative	Mean	5.857	5.974	*t* (36) = 0.215, *p* = .831, d = 0.071
	SD[range]	0.937 [2.88-6.88]	0.852[4.13-7.00]	
Self-enhancing	Mean	5.095	4.346	*t* (36) = 2.14, *p* = .104, d = 0.713
	SD[range]	1.019[3.13-6.63]	1.138[2.13-6.13]	
Aggressive	Mean	3.250	3.450	*t* (36) = 0.671, *p* = .676, d = 0.223
	SD[range]	0.879[1.75-5.00]	1.012[1.88-5.38]	
Self-defeating	Mean	3.988	4.677	*t* (36) = 2.106, *p* = .104, d = 0.702
	SD[range]	0.826[2.25-5.38]	1.185[3.00-6.63]	

Note. Statistics show the results comparing the two groups in the preference for each humor style. Reported *p*-values are adjusted by false discovery rate.

Supplementary Table 4. Results of simple linear regression model with BDI-II scores as a predictor.

Dependent variables	Coefficients (Beta)	R Square	*P*-value
P600 (non-ironic, left ROI)	-.178	.032	.258
P600 (non-ironic, right ROI)	-.044	.002	.794
P600 (ironic, left ROI)	-.254	.064	.124
P600 (ironic, right ROI)	.174	.030	.296
Zygomaticus activity (non-ironic)	.094	.009	.574
Zygomaticus activity (ironic)	.097	.009	.561
Corrugator activity (non-ironic)	-.051	.003	.762
Corrugator activity (non-ironic)	-.079	.006	.636
Valence ratings (non-ironic)	-.211	.045	.203
Valence ratings (ironic)	-.295	.087	.073

Supplementary Table 5. List and description of selected cognitive tests for principal component analysis, and factor loadings using an oblimin rotation with Kaiser Normalization on cognitive tests scores.

Cognitive test	Description	Principal component		
		Executive function	List memory	Semantic processing
TMT-A (s)	Connecting numbers by drawing straight lines between them in ascending order as fast and accurately as possible. This test measures sustained attention, cognitive flexibility, and hand motor speed.	-0.678	-0.003	-0.237
TMT-B (s)	Connecting numbers and letters by drawing straight lines between them in alternating order as fast and accurately as possible. Numbers are to be advanced in ascending order, while letters are to be connected in alphabetic order. This test measures divided attention, cognitive flexibility, and hand motor speed.	-0.811	0.068	-0.03
Similarities (p)	Identifying the qualitative relationship between two words. This test measures abstract thinking, verbal reasoning, and concept formatting.	0.727	0.167	-0.142
AVLT immediate (#)	Reading a list of 15 words repeatedly for five times. Reading another list of 15 words which serves as distractors. Recalling the words in the first list. This test measures immediate memory recall.	0.054	0.958	-0.097
AVLT delayed (#)	Recalling the words in the first list again after about one hour later. This test measures delayed memory recall.	-0.032	0.916	0.151
Logical memory immediate (p)	Listening to stories and repeating the stories immediately as accurately as possible. This test measures immediate auditory and declarative memory.	0.235	-0.029	0.870
Logical memory delayed (p)	Repeating the stories as accurately as possible after about one hour later. This test measures delayed auditory and declarative memory.	0.329	0.072	0.818
Fluency semantic-animals(#)	Naming words as fast as possible that belong to the animal category. This test measures semantic fluency.	-0.255	0.06	0.566

Note. TMT = Trail Making Test, AVLT = Auditory Verbal Learning Test, s = second, less means better, p = point, more means better, # = scores measured in the number of items. Factor loadings, for the component that the tests contribute most, are marked in bold.

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II

DECREASED INTERSUBJECT SYNCHRONY IN DYNAMIC VALENCE RATINGS OF SAD MOVIE CONTENTS IN DYSPHORIC INDIVIDUALS

by

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Decreased intersubject synchrony in dynamic valence ratings of sad movie contents in dysphoric individuals

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Emotional reactions to movies are typically similar between people. However, depressive symptoms decrease synchrony in brain responses. Less is known about the effect of depressive symptoms on intersubject synchrony in conscious stimulus-related processing. In this study, we presented amusing, sad and fearful movie clips to dysphoric individuals (those with elevated depressive symptoms) and control participants to dynamically rate the clips' valences (positive vs. negative). We analysed both the valence ratings' mean values and intersubject correlation (ISC). We used electrodermal activity (EDA) to complement the measurement in a separate session. There were no group differences in either the EDA or mean valence rating values for each movie type. As expected, the valence ratings' ISC was lower in the dysphoric than the control group, specifically for the sad movie clips. In addition, there was a negative relationship between the valence ratings' ISC and depressive symptoms for sad movie clips in the full sample. The results are discussed in the context of the negative attentional bias in depression. The findings extend previous brain activity results of ISC by showing that depressive symptoms also increase variance in conscious ratings of valence of stimuli in a mood-congruent manner.

Depressive disorder is a mental health disorder that causes patients to exhibit a unique combination of affective, cognitive and somatic symptoms[1]. According to cognitive theories of depression[2,3], depressive disorder is associated with an attentive negative bias in information processing that causes individuals to exhibit selective attention to dysphoric stimuli, ruminate on self-referential depressive thoughts and recall sad memories.

Several empirical studies support the presence of attentive negative processing bias in individuals with pre-clinical and clinical depression. Studies using reaction time paradigms, such as the dot-probe task and emotional Stroop task, have consistently reported a negative bias towards sad faces and other dysphoric contents in these individuals[4,5]. Eye tracking studies have similarly demonstrated increases in gaze maintenance on dysphoric stimuli in pre-clinical and clinical depression cases[6,7]. Studies using event-related potentials have revealed a depression-related negative bias in emotional face processing[8–11]. Depressed participants also rate neutral faces as sad more often than controls[12,13]. However, naturalistic stimuli rarely appear in depression studies on negative bias, although they would allow a more ecologically valid approach than, for example, the presentation of static pictures.

In response, in this study we investigate whether depressive symptoms affect the dynamic valence ratings of emotional movie clips. We are particularly interested in the ratings' intersubject correlation[14,15] (ISC), which reflects how similarly people evaluate stimulus content. Group differences in ISC, specifically when viewing sad movies, can be expected due to depression-related attentive bias[2,3]. Previous studies have not investigated the ISC of emotional movie contents' dynamic valence ratings neither in healthy nor depressive participants. However, for healthy participants, some studies have investigated valence rating ISC for the subjective emotions that naturalistic stimuli elicited[16], and for eye movements during movie watching[17].

Findings from brain activity measurements indicate that, in healthy individuals, brain activity patterns during movie watching are surprisingly similar across participants[18–27]. ISC in neural responses has been found to be affected by, for instance, valence and arousal from emotional events[20], attentional engagement with stimuli[23–25]

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and emotional involvement[23] regarding the stimuli. In individuals with neuropsychiatric disorders, meanwhile, within-group neural synchrony during natural stimulation seems to be lower[28–34]. Studies have reported weaker temporal synchronization compared to neurotypical controls in participants with autism[28,29], schizophrenia[31,32] and major depressive disorder (MDD)[33,34]. When depressed participants viewed films with negative emotional valence, they exhibited weaker fMRI response synchronization as well in several neural networks associated with sensory and emotional functions and attention, as compared to controls[33]. Furthermore, in adolescents, those who had more severe depressive symptoms exhibited less similar fMRI responses to an emotional movie clip[34].

With this study, we complement previous brain activity findings[33,34] by investigating dysphoric participants' (individuals with elevated depressive symptoms) dynamic valence rating ISC for emotional movie clips in comparison to controls. We anticipated lower valence rating ISC in the dysphoric rather than the control group based on previous findings demonstrating decreased ISC for neural activity in non-neurotypical samples[33,34].

We utilized amusing, fearful and sad movie clips as stimuli. We expected lower ISC in the dysphoric group particularly for sad movie clips because of the mood-congruent attentive bias associated with depression[8–11]. Amusing movie clips were selected to study whether ISC decreased for positive valence stimuli as well, while fearful movie clips were used to study whether ISC decreased for negative stimuli in general or specifically for mood-congruent (sad) stimuli. Cognitive theories of depression suggest that depression-related negative schemata activate negative self-referential information, automatic thoughts and memories, which produce unique and subjective emotional experiences[35]. These can affect how movie content valence is evaluated. Since the activation of depression-related negative schemata is likely to cause individual variability in reactions, sad movie clips could evoke more heterogenous activity (i.e. lower ISC) in the dysphoric group than in the control group.

Previous studies have shown that stimuli with high emotional arousal attract participants' attention[36]. Therefore, to examine emotional arousal to movie clips, we applied electrodermal activity (EDA) to measure the participants' phasic responses during the viewing as well[37]. These data can inform us in our interpretation of the valence rating ISC results.

Results

First, we report the mean values of the EDA responses and dynamic behavioural ratings to amusing, fearful and sad movie clips, and compare the responses between the dysphoric and control participants. Then, we outline the comparison of the dynamic behavioural ratings' ISC for emotional movie clips in the dysphoric and control groups.

Electrodermal activity (EDA). *Mean phasic EDA values.* For the mean phasic EDA values in response to emotional movie clips, the analysis of variance (ANOVA; Movie type × Group) showed a main effect for Movie type ($F(2,40) = 8.26$, $p = 0.001$, $\eta_p^2 = 0.292$). Paired samples t-tests showed a larger amplitude in phasic EDA to fearful ($M = 0.134$ µS, $SD = 0.145$) than sad ($M = 0.095$ µS, $SD = 0.124$) movie clips ($t(42) = 3.78$, $p < 0.001$, 95% confidence interval (CI) [− 0.060, − 0.018], d = 0.29). When comparing amusing ($M = 0.106$ µS, $SD = 0.135$) and fearful or amusing and sad movie clips, there were no differences between clips ($p > 0.095$, 95% CI [− 0.056, 0.004] and $p > 0.156$, 95% CI [− 0.005, 0.033], respectively). There were no main effects for Group or interaction effects for Group × Movie type, with all p-values > 0.818. Figure 1 illustrates the mean phasic EDA values during emotional movie watching.

Because a few participants also had anxiety symptoms, we investigated if the main effect of Movie type reflecting the largest EDA amplitudes to fearful movie clips was explained by anxiety symptoms. We thus conducted an analysis of covariance (ANCOVA; Movie type × Group) controlling for anxiety (Anxiety in Depression, Anxiety, Stress Scales, or DASS-A, scores) symptoms. The main effect of Movie type remained significant ($F(2,39) = 10.36$, $p < 0.001$, $\eta_p^2 = 0.347$), suggesting that anxiety symptoms did not explain the EDA to fearful movie clips. There was also no main effect for Group or an interaction effect for Group × Movie type ($p > 0.117$).

Correlations. There were no correlations between phasic EDA and Beck's Depression Inventory-II (BDI-II) scores for any of the movie types in the control group (all p-values > 0.736, False discovery rate (FDR) corrected), the dysphoric group (all p-values > 0.999, FDR corrected) or the whole sample (all p-values > 0.999, FDR corrected).

Behavioural valence rating. *Mean valence rating values.* Figure 2 shows the dynamic behavioural evaluations of movie valence separately for each movie and research group. Figure 2 also provides descriptive information on the dynamic changes at the grand-average level. The results of the mean valence rating values are presented in Fig. 3.

For the mean behavioural valence rating values, the ANOVA (Movie type × Group) revealed a main effect for Movie type ($F(2,37) = 58.36$, $p < 0.001$, $\eta_p^2 = 0.759$). We conducted pairwise comparisons with Bonferroni correction separately between amusing and sad, amusing and fearful, and sad and fearful movie clips. Amusing ($M = 84.1$, $SD = 136.2$) movie clips were evaluated as more positive than sad ($M = -272.8$, $SD = 160.1$) movie clips ($t(39) = 10.90$, $p < 0.001$, 95% CI [290.6, 423.0], d = 2.40). Amusing movie clips were also rated more positively than fearful ($M = -306.6$, $SD = 191.9$) movie clips ($t(39) = 10.23$, $p < 0.001$, 95% CI [313.4, 467.9], d = 2.35). There was no difference between sad and fearful movie clips ($p > 0.087$, 95% CI [− 5.27, 72.89]). The main and interaction effects for Group were not significant (all p-values > 0.599).

Next, the ANCOVA (Movie type × Group) controlling for anxiety symptoms (DASS-A) revealed that the main effect of Movie type remained significant ($F(2,74) = 55.90$, $p < 0.001$, $\eta_p^2 = 0.602$). There was also no main effect for Group or an interaction effect for Group × Movie type ($p > 0.757$).

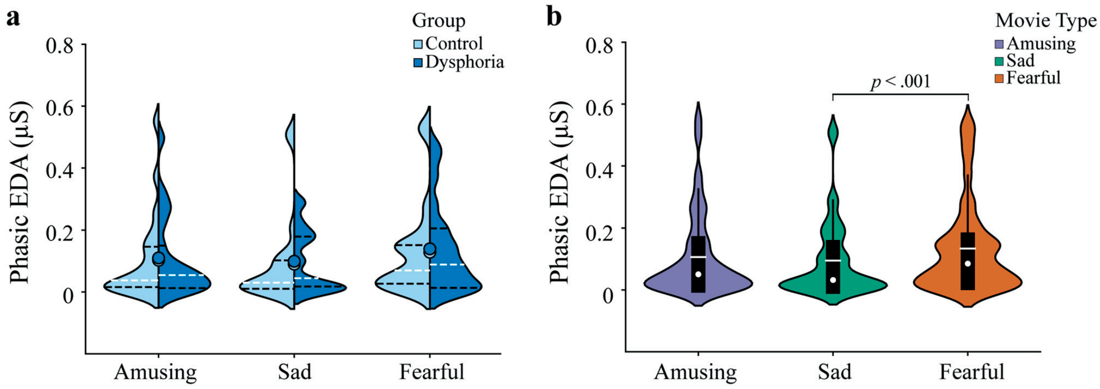

Figure 1. Violin plots for the mean phasic EDA values averaged over the timepoints separately for each movie type. For both (**a,b**), violin plot outlines illustrate the distribution of EDA estimates using kernel probability density with the bandwidth of 0.2. Wider area of the violin plot represents a higher probability of the values that the EDA take on, and the thinner area corresponds to a lower probability. Please note that the negative values in the violin plot are the estimations of values of the EDA data, which is caused by the use of kernel density estimation. (**a**) The mean phasic EDA values to each movie type in each group (no significant group differences). Each side of the violin corresponds to a different group. Dots denote mean of the EDA. Horizontal white dotted lines show median of the EDA and horizontal black dot lines represent the interquartile range (IQR) of the EDA. (**b**) The mean phasic EDA values to each movie type averaged over the control and dysphoric groups. White dots on the violin plots show the median of the EDA and horizontal white lines represent the mean of the EDA. The black bars in the centre of violins denote the IQR of the EDA. The black lines stretched from the bars show the lower and upper adjacent values (1.5 times the IQR) of the EDA, respectively.

Behavioural valence rating ISC. The results of the valence rating ISC are illustrated in Fig. 4.

For valence rating ISC, a repeated-measures ANOVA (Movie type × Group) showed a main effect for Movie type ($F(2,76) = 97.20$, $p < 0.001$, $\eta_p^2 = 0.719$) and Group ($F(1,38) = 8.70$, $p = 0.005$, $\eta_p^2 = 0.186$). The main effects were modulated by an interaction effect between Movie type and Group ($F(2,76) = 9.38$, $p < 0.001$, $\eta_p^2 = 0.198$). Independent *t*-tests with Bonferroni correction investigated this interaction effect by comparing the dysphoric and control groups' responses to the amusing, sad and fearful movie clips. This demonstrated a significant group difference in ISC for sad movie clips ($t(38) = 6.23$, $p < 0.001$, 95% CI [0.125, 0.245], d = 2.02). The ISC was also larger in the control group ($M = 0.542$, $SD = 0.102$) than in the dysphoric group ($M = 0.357$, $SD = 0.084$). There were no differences in ISC for amusing and fearful movie clips between the dysphoric and control groups (all *p*-values > 0.295).

Next, we compared valence rating ISC for the amusing, sad and fearful movie clips in separate repeated ANOVA within the dysphoric and control groups. For the dysphoric group, the main effect of Movie type was significant ($F(2,36) = 25.83$, $p < 0.001$, $\eta_p^2 = 0.589$). The effect of anxiety symptoms was also investigated in the dysphoric group, though the ANCOVA with DASS-A as a covariate showed no significant Movie type × DASS-A interaction in the dysphoric group ($p = 0.348$). An ANCOVA with Medication as a covariate also showed no significant interaction between Movie type and Medication ($p = 0.058$) in the dysphoric group. Follow-up paired-samples *t*-tests with Bonferroni correction showed that the dysphoric group had larger ISC in the behavioural ratings of sad movie clips ($M = 0.357$, $SD = 0.084$) than amusing clips ($M = 0.176$, $SD = 0.130$; $t(18) = 5.35$, $p < 0.001$, 95% CI [− 0.252, − 0.110], d = 1.65). The behavioural rating ISC for fearful movie clips ($M = 0.386$, $SD = 0.120$) was also larger than for amusing clips in the dysphoric group ($t(18) = 6.47$, $p < 0.001$, 95% CI [− 0.278, − 0.142], d = 1.68). No difference in ISC emerged between sad and fearful movie clips ($p = 0.323$).

For the control group, a repeated-measures ANOVA showed a main effect for Movie type ($F(2,40) = 93.32$, $p < 0.001$, $\eta_p^2 = 0.824$). Subsequent t-tests with Bonferroni correction indicated that the control group had a larger valence rating ISC for sad move clips ($M = 0.542$, $SD = 0.102$) than for amusing ones ($M = 0.201$, $SD = 0.108$; $t(20) = 15.56$, $p < 0.001$, 95% CI [− 0.388, − 0.296], d = 3.25). The controls also had a larger valence rating ISC for fearful movie clips ($M = 0.432$, $SD = 0.146$) than for amusing clips ($t(20) = 7.10$, $p < 0.001$, 95% CI [− 0.300, − 0.163], d = 1.80). The valence rating ISC was thus larger for sad movie clips than fearful ones ($t(20) = 5.46$, $p < 0.001$, 95% CI [0.068, 0.153], d = 0.87).

Correlations. For the control group, no significant correlations emerged between the mean valence rating values and number of depressive symptoms for any movie type (all *p*-values > 0.629, FDR corrected). For the dysphoric group, there was a negative relationship between the mean valence rating values for amusing movie clips and number of depressive symptoms ($r = -0.639$, $p = 0.003$ (FDR corrected $p = 0.017$), 95% CI [− 0.834, − 0.206]): the more depressive symptoms the participants had, the less positive they evaluated the amusing movie clips. There were no correlations between BDI-II scores and mean valence rating values for sad and fearful movie clips (all *p*-values > 0.999, FDR corrected). For the whole sample, Spearman's rank correlation test

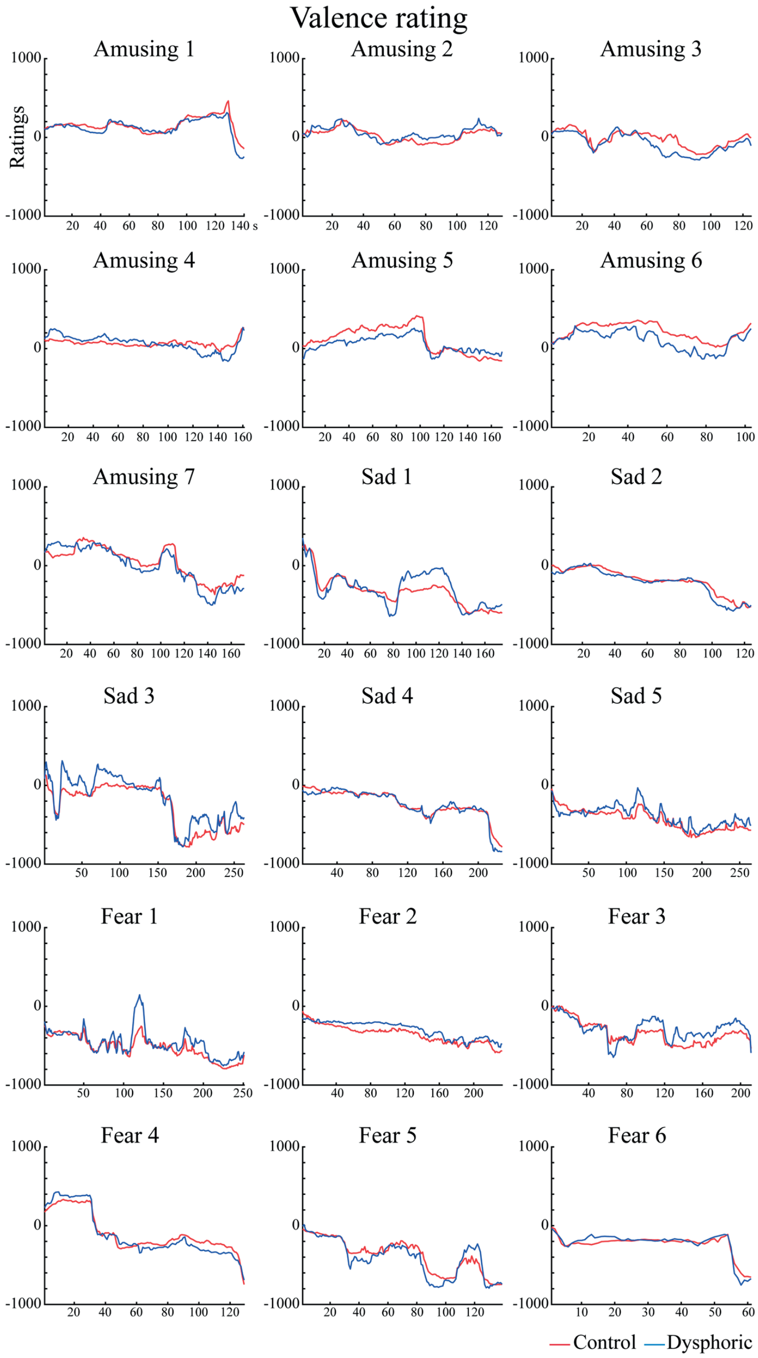

Figure 2. Dynamic valence ratings separately for each movie and research group. Here the ratings range from −1000 to 1000 on an artificial scale. Data of movie Amusing 3 were excluded for the statistical analysis of the EDA responses and valence ratings, because the average value over the timepoints for valence for this amusing movie clip was negative.

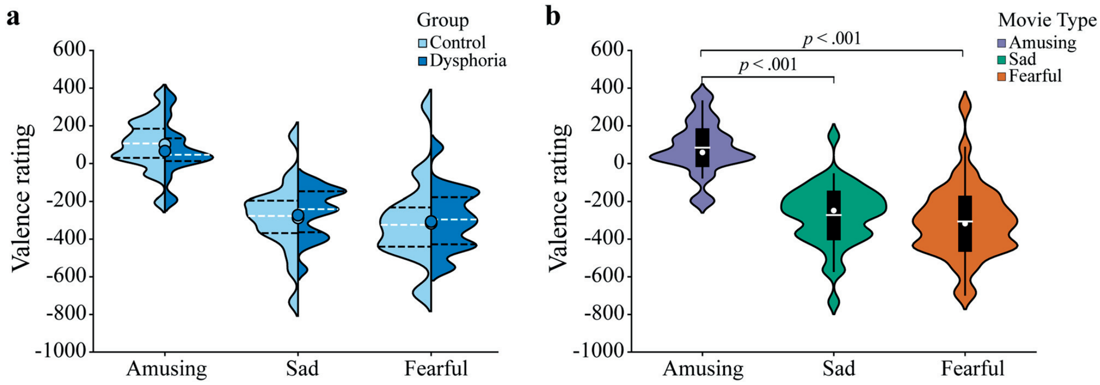

Figure 3. Violin plots for the valence ratings averaged over the timepoints separately for each movie type. For both (**a**,**b**), violin plot outlines illustrate the distribution of valence rating estimates using kernel probability density with the bandwidth of 0.2. Wider area of the violin plot represents a higher probability of the values that the valence ratings take on, and the thinner area corresponds to a lower probability. (**a**) The mean valence rating values to each movie type in each group (no significant group differences). Each side of the violin corresponds to a different group. Dots denote means of the valence rating. Horizontal white dotted lines show median of the valence rating and horizontal black dot lines represent the interquartile range (IQR) of the valence rating. (**b**) The mean valence rating values to each movie type averaged over the control and dysphoric groups. White dots on the violin plots show the median of the valence rating and horizontal white lines represent the means of the valence rating. The black bars in the centre of violins denote the IQR of the valence rating. The black lines stretched from the bars show the lower and upper adjacent values (1.5 times the IQR) of the valence rating, respectively.

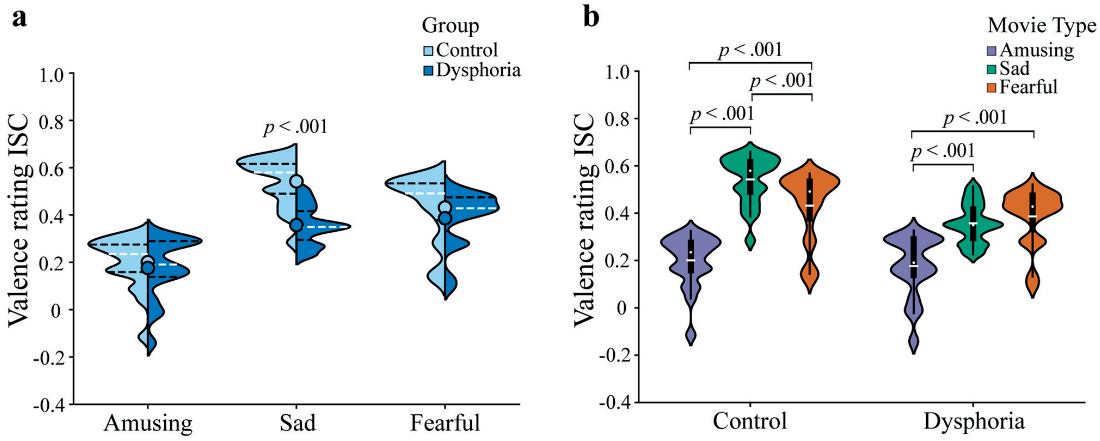

Figure 4. Violin plots for the valence rating ISC for each movie type and research group. For both (**a**,**b**), violin plot outlines illustrate the distribution of ISC estimates using kernel probability density with the bandwidth of 0.2. Wider area of the violin plot represents a higher probability of the ISC, and the thinner area corresponds to a lower probability. (**a**) Group differences in each movie type are illustrated. Each side of the violin corresponds to a different group. Dots denote means of the ISC. Horizontal white dotted lines show median of the ISC and horizontal black dot lines represent the interquartile range of the ISC. (**b**) Differences of movie type within control and dysphoric group are shown. White dots on the violin plots show the median of the ISC and horizontal white lines represent the means of the ISC. The black bars in the centre of violins denote the interquartile range (IQR) of the ISC. The black lines stretched from the bars show the lower and upper adjacent values (1.5 times the IQR) of the ISC, respectively.

showed no correlations between the valence ratings and number of depressive symptoms for any movie type (all p-values > 0.505, FDR corrected).

The correlations between valence rating ISC and BDI-II scores were non-significant for each movie type in the control group (all p-values > 0.955, FDR corrected) and the dysphoric group (all p-values > 0.999, FDR corrected). For the whole sample, Spearman's rank correlation test revealed a negative relationship between valence rating ISC and number of depressive symptoms during the viewing of sad movie clips ($r = -0.552$, $p < 0.001$ (FDR corrected $p < 0.005$), 95% CI [− 0.754, − 0.281]): the more depressive symptoms the participants had, the less synchronized they were in their valence ratings of sad movie clips. There were no relationships between valence rating ISC and BDI-II scores for amusing and fearful movie clips (all p-values > 0.208, FDR corrected).

Discussion

In the present study, by applying ISC analysis, we compared dysphoric and non-dysphoric participants' ISC in their behavioural valence ratings of emotional movie clips. We found that dysphoric participants were less synchronized than controls in their dynamic valence ratings, specifically for sad movie clips.

A previous study showed increased heterogeneity in the synchrony of depressed participants' fMRI responses to movies in several neural networks associated with sensory and emotional functions, as well as attention[33]. These authors suggested that decreased ISC in the depressed group could be related to their unique and distinct internal processes evoked by the movie clips. This is a plausible explanation in this study as well for the decreased synchrony in the behavioural valence ratings of movies in participants with depressive symptoms. It is also possible that in the control group, the valence ratings were more consistent since they reflected more stimulus-dependent reactions evoked by the movie contents, while the dysphoric group's ratings could reflect more participant inner processes, such as evoked memories and emotions. The exact mechanism underlying the dysphoric group's rating desynchronization is unclear, however. It is possible that the memories and emotions evoked by the sad movie clips interrupted their rating behaviour, causing more mind wondering than in the control participants. There could also have been more internal elaborative processing in the dysphoric group, such as intense emotion regulation or rumination[38,39]. In our previous eye tracking study[40], where participants freely viewed video-recorded emotional and neutral dyadic conversations, the more depressive symptoms the participants had, the less viewing patterns aligned with the conversation flow the correlative analysis showed. This finding reflects depressed participants' difficulties with attentively following social interactions. Notably, social interactions were also depicted in many of the movie clips in this present study. However, it is unclear whether the results of this study reflect increased synchrony specifically in contents related to social interactions.

Instead, our data demonstrated a depression-related effect specifically in the ISC for sad movie ratings: the ISC was lower in the dysphoric group for sad clips, but no such effect emerged for fearful or amusing clips. In addition, our data showed that for the whole sample, the more depressive symptoms the participants had, the less synchronized they were in their valence ratings of sad movie clips. We expected this based on the mood-congruent attentive bias in individuals with depression[2,3]. Our finding on behavioural movie valence rating ISC is in line with a previous fMRI study showing that participants with MDD had less synchronized fMRI responses compared to control participants when viewing movies with negative emotional valence[33]. However, in that study[33], negative movie contents were not divided into separate categories (e.g. sad and fearful), but mixed. Concordant with our expectations for sad attentive bias in depression, we did not find any group differences in ISC for fearful movie clips. Indeed, bias towards threatening content is not a common finding in depressive populations, but more associated with anxiety[4,41] (see, however, Rantanen et al.[42] for depression-related attentive bias to interpersonally aggressive pictures). For this reason, we did not expect group ISC differences for fearful movie clips.

ISC was also similar in the groups' ratings of amusing movie clips. Some previous studies have shown less positive expressive behaviour and subjective reports in response to pleasant films and scenes in depressed individuals compared to controls[43,44]; blunted positive emotional reactions in general have also been reported in depression cases[45]. In our study, the participants rated the movie clips' valence rather than their own subjective emotions. Our results suggest that the ISC of these stimulus-related valence ratings are observable in sad, but not for fearful or amusing, movie clips. It is also notable that the mean dynamic valence rating values did not differ for any of the movie types between the groups, only in ISC.

Previous studies have stated that high emotional stimuli arousal cause attentional capture[36,46], which increases intersubject synchrony in brain activity[20]. It is thus possible that the present study's group difference in rating ISC for sad movie clips is explained by different levels of arousal from the different movie types. However, this seems not to be the case in light of the EDA recordings, reflecting emotional arousal[37], in which no group differences emerged. Additionally, at the whole sample level, a smaller amplitude in phasic EDA for sad movie clips than for fearful ones indicated the participants' lower arousal from the former.

In both groups, the dynamic valence rating ISC was lowest for the amusing movie clips. A previous study found that a negative stimulus valence is associated with increased ISC in brain activity in the default-mode network and limbic system[20]. In addition, research has suggested that negative emotions urge people to narrow their mental focus for immediate survival benefits, while positive emotions broaden people's attention and promote play and exploration[47,48]. Therefore, broader attention to amusing movie scenes than to negative-valence scenes, and thus more variable viewing pathways, could explain the lower valence rating ISC for amusing clips.

In general, our results are consistent with previous neuroimaging findings in autism, schizophrenia and melancholic MDD, which have shown less fMRI response synchronization in multiple cortical areas during naturalistic stimulation in these groups compared to neurotypical samples[28–30,32,33]. It is understandable that neurodevelopmental and psychiatric disorders can increase variability between individuals in brain function due to "noisier" neural processes. Here, we demonstrate a similar increase in variability at the behavioural level in conscious ratings of valence of dynamic visual stimuli.

The present study has a few limitations. First, we used silent movie clips without captions. Therefore, the emotions evoked by the clips may not have been as strong as those evoked by clips with captions or background music, speech and other sounds. The missing audio might also have caused difficulties in interpreting the plot, because some of the scenes contained conversations. We did not want to use sounds because spoken non-native language could have confused the participants, and differences in their linguistic abilities could have caused some group differences. Further, captions could have guided spatial attention away from the natural targets of attention in the visual scene. We aimed to counteract the effects of the missing audio by providing the participants a short explanation of the current situation in the movie before showing each clip. Another limitation is that 9 of the 21 dysphoric participants were taking anti-depressant medication during the study, though the covariate analysis did not reveal an effect for medication. Several dysphoric participants also had some anxiety symptoms during the study. The analysis with anxiety symptoms (DASS-A) as a covariate, however, suggested that anxiety did not affect the results. Lastly, although all the selected movie clips were rated for discrete emotional feelings and categorized into amusing, sad and fearful movie types in a previous study[49], our participants rated them only on a negative–positive valence scale, and categorization was not requested. It is also worth noting that compared to the previous study[49], we played the movie clips without sound, and some parts of the scenes were cut. Therefore, the original categorizing into emotional categories may not be preserved exactly as in Schaefer et al.[49].

In conclusion, the present study investigated intersubject synchronization across dysphoric and control participants as they rated the valence of amusing, sad and fearful movie clips. The dynamic valence rating ISC of sad clips was lower in the dysphoric group compared to the control group, most probably reflecting negative attentive bias related to depression symptoms. The findings of the present study provide the first evidence of a reduction in within-group synchrony in behavioural valence ratings due to depressive symptoms.

Methods

Participants. The required sample size for the present study was computed with an a priori power analysis using G*Power[50] (version 3.1.9.2). We selected a repeated-measures ANOVA to test the interaction between a within-subject variable (Movie type) and a between-subject variable (Group). As no previous study has investigated valence rating ISC in depression (or valence rating ISC of dynamic stimuli in general), the sample size in the present study was estimated based on a conventional large effect size[51] ($\eta_p^2 = 0.14$) using the specifications in SPSS (IBM SPSS Statistics; IBM Corporation, NY, USA). Based on this calculation, 19 participants were required for each group (healthy and dysphoric) to achieve a statistical power of $(1 - \beta) = 0.85$, a significance level of $\alpha = 0.05$ and a non-sphericity correction of $\varepsilon = 1$. This sample size is larger than in some previous fMRI studies with clinical populations[28,29], but similar to the sample sizes in a depression-related study[33].

In total, 24 healthy (4 males and 20 females) and 23 dysphoric (8 males and 15 females) Finnish-speaking participants were recruited for the study. All participants were recruited through flyers distributed around the Jyväskylä area and via the student email lists of the University of Jyväskylä. The study protocol occurred 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 participants before measurement began.

The inclusion criteria were right-handedness, normal vision and hearing ability, and age between 18 and 40 years. Participants who had brain damage, neurological disorders or a history of drug or alcohol abuse were excluded. Another exclusion criterion was current or previous psychiatric disorders and symptoms, except for depression and anxiety symptoms in the dysphoric group. Depressive symptoms were measured with a self-report inventory of depressive symptoms, the BDI-II[52]. Participants with BDI-II scores of 14 or higher were included in the dysphoric group, and participants with BDI-II scores less than 10 were included in the control group.

Some, but not all, of the dysphoric participants had current depression diagnoses. Seven participants were interviewed by a medical doctor independent of the study, and their depression diagnoses were confirmed at the beginning of the study. Eight participants self-reported having a current diagnosis of depression. Six dysphoric participants did not have a depression diagnosis. For all dysphoric participants, the BDI-II score range was 16–45.

One dysphoric participant was excluded due to failure to meet the inclusion criteria, and 2 controls and 1 dysphoric participant could not be included in the final sample due to artefacts in their psychophysiological recordings. Therefore, 22 control (4 males and 18 females) and 21 dysphoric (7 males and 14 females) participants were included in the EDA data analysis. For the behavioural ratings, the data of 3 more participants were lost due to a technical problem. Thus, in the final sample for the analysis of behavioural ratings, there were 21 controls (4 males and 17 females, age range 19–40 years, $M = 26.86$ years, $SD = 6.64$, BDI-II scores range 0–5) and 19 dysphoric participants (7 males and 12 females, age range 18–40 years, $M = 30.00$ years, $SD = 7.65$, BDI-II scores range 16–45). The participants' demographic and clinical information for the EDA analysis is presented in Table 1.

Stimuli and experimental design. Amusing, sad and fearful movie clips were selected from the database of a previous study[49]. We selected movie clips from each emotional category (amusing, sad and fearful) based on the emotional feeling ratings that the participants of that study self-reported while watching them[49]. Movie clips with the most intensive emotional feelings were selected. Parts of the scenes were cut to avoid extremely strong depictions (e.g., violence) that were irrelevant to the target emotional categories. Because the dialogue in the movie clips was in English or French, and the participants were native Finnish speakers, all clips were presented without sound. Captions were not used, because they could affect the participants' spatial attention to the visual scenes. The arousal score of each movie clip, as reported in Schaefer et al.[49], is reported in Supplementary Table 1. According to the results of Schaefer et al.[49], the mean arousal score of the selected movie clips is 5.478 for sad clips, 4.255 for amusing clips and 4.825 for fearful ones (per a 7-point scale, 1 = *no emotion at all*, 7 = *very intensive emotion*). To keep the total clip duration of each emotion category similar, different numbers of movie clips were used, totalling at 7 amusing, 5 sad and 6 fearful movie clips. For each emotional category, there was approximately 17 min' worth of clips. Supplementary Table 1 presents descriptive information about the selected movie clips.

Characteristics		DYS (n = 21)	CTRL (n = 22)	Statistics
Age (year)	Mean	30.29	26.68	$t(41) = 1.692$, $p = .098$
	SD (range)	7.42 (18–40)	6.54 (19–40)	
Level of Education[a]	Low	1	0	$x^2(2) = 4.410$, $p = .110$
	Medium	11	6	
	High	9	16	
Gender	Male	7	4	$x^2(1) = 1.296$, $p = .255$
	Female	14	18	
DASS-A	Mean	9.76	1.50	$t(41) = 4.829$, $p < .001$
	SD (range)	7.58 (1–38)	2.58 (0–10)	
BDI-II	Mean	29.43	2.00	$t(41) = 15.315$, $p < .001$
	SD (range)	8.02 (16–45)	1.77 (0–5)	
Severity of Depression[b]	No diagnoses	6	Na	Na
	Mild (F32.0)	0	Na	Na
	Moderate (F32.1)	6	Na	Na
	Recurrent moderate (F33.1)	1	Na	Na
	Severe (F32.2)	1	Na	Na
	Recurrent severe (F33.2)	4	Na	Na
	Severity unknown	3	Na	Na
Depression Medication[c]	No medication	12	Na	Na
	SSRI	4	Na	Na
	SNRI	1	Na	Na
	Other	4	Na	Na

Table 1. Demographic and clinical information for each group. Statistics present independent t-test or x^2 test values investigating the group differences. *DYS* dysphoric group, *CTRL* control group, *SD* standard deviation, *BDI-II* Beck's Depression Inventory, Second Edition, *DASS-A* Depression, Anxiety, Stress Scales, Anxiety scale (Lovibond and Lovibond 1995). [a]Low = education level under high school, Medium = education level at high school or vocational school, High = education level at university. [b]Depression severity based on participants self-report on their diagnosis or diagnosis given by project doctor. The diagnosis of depression was in accordance with the International Classification of Diseases and Related Health Problems, 10th Revision (ICD-10; World Health Organization, 2010) criteria. There is missing information related to disease severity from three participants, which is reported as severity unknown. [c]*SSRI* selective serotonin reuptake inhibitor, *SNRI* serotonin and norepinephrine reuptake inhibitor, *Other* other antidepressant medication.

The clips' presentation was controlled with E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA, USA). The movie clips were separated into three blocks corresponding to the three emotional dimensions (amusing, sad and fearful). The order of the blocks was counterbalanced between the participants. Within each block, clips in the same emotional dimension were presented randomly. Since we presented movie clips instead of whole movies, and the clips that were cut from the movies may be difficult to understand without context, we provided the participants a written introduction to the plot of the film before each clip. The text was written on the screen (Supplementary Table 2). After reading the introduction, the participants pressed a button to play the clip. Following a central fixation mark (1500 ms in duration), the movie clip was displayed at the centre of the screen at a resolution of 768 × 540 pixels. A blank screen was presented for 4500 ms after each movie clip. There was a 5-min break before the next block began. The experiment procedure is illustrated in Fig. 5.

Psychophysiological and behavioural measurements were conducted for every participant on two separate days. This procedure followed that of previous fMRI studies[20,53] exploring inter-subject synchronization of neural responses to emotional stimulation, in which participants were rating their experience (valence/arousal) in a separate session from the brain activity recording. Here, it was also advisable to conduct the recordings of the brain activity and valence rating on separate days, because muscle activity (here caused by use of a joystick in valence rating task) can cause artefacts to electroencephalography (EEG) data[54].For all participants, the psychophysiological measures were conducted on the first day and the rating task on the second day. We chose this order because it allowed the participants to naturally watch the movie clips during the psychophysiological measurements without thinking of their valence or memories from the rating task (which could have happened if they rated the clips first). Important to note, repeated viewing of emotional stimuli has only a small effect on the valence rating when stimuli contents are rated[55].

On the first measurement day, EEG (these data are not reported here) and EDA data were collected as the participants watched the movie clips. The participants were seated in a sound- and electricity-shielded room with a dim light on the ceiling. A 23-inch screen (Asus VG236H, 1920 × 1080 pixels) was placed approximately 1 m in front of the participant to display the movie clips. Before the measurement began, the participants were aware that they were going to watch movie clips that may contain emotional scenes. However, the emotional

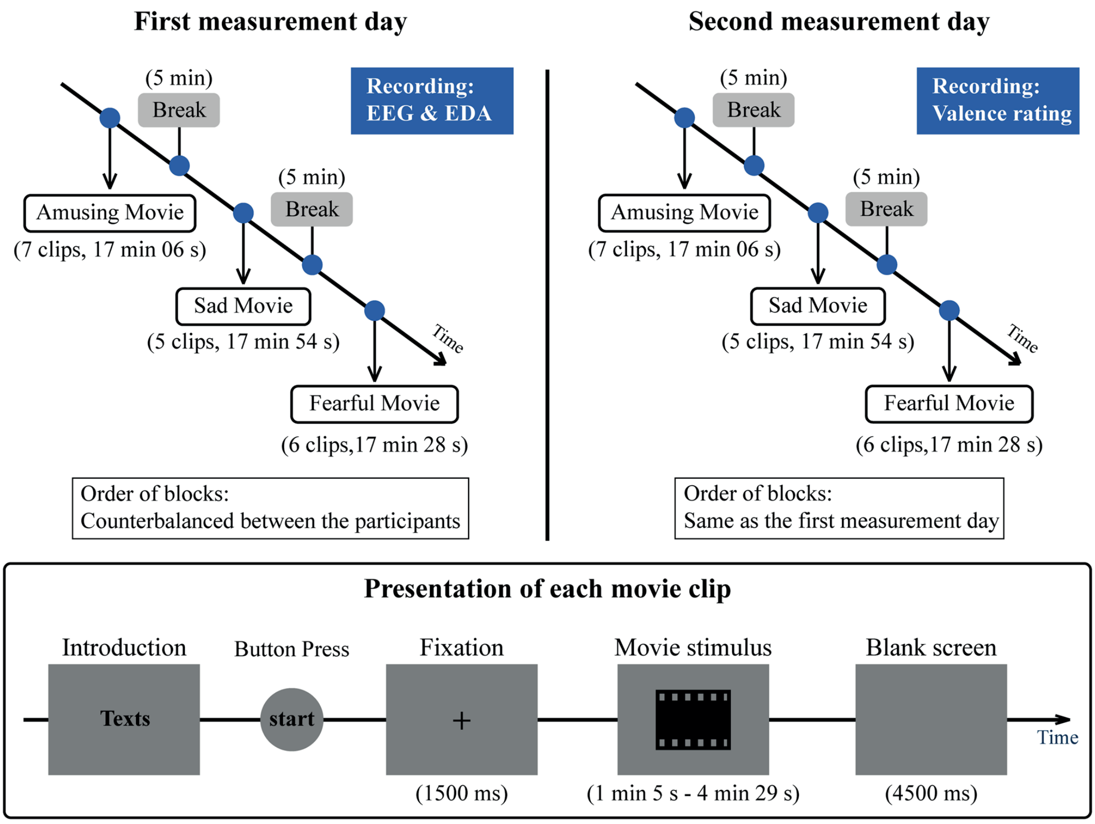

Figure 5. Experimental design. Psychophysiological and behavioural measurements were conducted for every participant on two separate days. Clips in the same emotional category were presented randomly. *EEG* electroencephalography; *EDA* electrodermal activity. EEG is not reported in the present paper.

categories were not revealed. The participants were instructed to sit still in a relaxed position during the movie screening, and they were told that they could end the experiment at any time.

On the second measurement day, the movie clips' dynamic behavioural valence ratings (positive vs. negative) were recorded. By moving a joystick forward or backward, the participants evaluated the scenes' valences on a continuous scale. Before the measurement began, the participants were instructed to practise for a few minutes so that they were familiar with the use of the joystick. There was a break after each movie clip, and the participants could start the rating for the next movie clip whenever they were ready. For each participant, the order of the blocks and movie clips was same as in the psychophysiological recordings.

Recording and analysis of EDA data. *EDA data recording.* A continuous EDA was measured and amplified with a NeurOne system (Bittium Biosignals Ltd, Kuopio, Finland). Two disposable isotonic gel electrodes (Ag/AgCl, EL507, Biopac Systems, INC.) were placed on the participant's nondominant hand (left hand). One of the electrodes was placed below the first digit (thenar eminence on the palm) and the other was attached on the same horizontal level below the fourth digit (hypothenar eminence on the palm). The electrodes were connected to a galvanic skin conductance module (Brain Products, Gilching, Germany) utilizing a constant current source with 0.5 V amplitude. The signal was recorded at a sampling rate of 1,000 Hz in DC mode, with a high cut-off of 250 Hz.

EDA data pre-processing. The EDA data were analysed using a MATLAB (R2016b) toolbox, Ledalab (Version 3.4.9). First, the sampling rate was reduced to 10 Hz. Next, adaptive smoothing was conducted to reject artefacts. Continuous decomposition analysis[56] as performed to extract continuous phasic activity signals from the EDA responses as well. Then, the mean phasic EDA values were calculated for each movie clip and each participant. Lastly, for each participant, the phasic EDA in response to the movie clips was averaged for each movie type.

Movie type	Code of the movie	Mean	Standard deviation
Amusing	1	135.62	179.99
	2	42.07	141.26
	3	−46.47	264.11
	4	68.76	202.74
	5	78.95	196.37
	6	162.24	188.18
	7	16.79	250.85
Sad	1	−302.11	195.61
	2	−201.97	155.54
	3	−215.67	218.90
	4	−237.21	194.37
	5	−406.84	249.45
Fearful	1	−481.56	238.87
	2	−321.02	254.69
	3	−312.15	248.68
	4	−111.39	249.99
	5	−385.30	251.90
	6	−228.00	192.13

Table 2. Mean values of the behavioural valence ratings for each movie clip (ratings ranging from − 1000 to 1000 on an artificial scale). Amusing movie with code 3 was excluded from all the analysis due to negative mean value of the valence rating.

Recording and analysis of valence rating. *Valence ratings recording.* The behavioural valence evaluation of each movie clip was recorded on the second day of measurement. The participants were instructed to evaluate the valence (positive, negative or neutral) of the scene content on a continuous scale by moving a joystick (Extreme 3D Pro, Logitech, Europe S.A.) forward or backward. The joystick was connected to E-Prime 2.0 software to control the presentation of movie clips and record the continuous valence ratings. The participants' ratings were recorded at a 4 Hz sampling rate, ranging from − 1000 to 1000 on an artificial scale. To avoid possible response biases, for half of the participants, pushing the joystick forward rated a scene as positive, and pulling it backward rated the scene as negative. For the other half, this assignment was reversed.

Valence rating analysis. The behavioural valence ratings were analysed with a custom-made MATLAB (R2016b) script. Behavioural valence rating data were down-sampled to 1 Hz. To start, the mean valence rating value for each movie clip was calculated for all participants (Table 2). Based on the participants' ratings, data from the movie clips were reselected for further analysis. For each amusing movie clip, the average valence rating should be positive; for each sad and fearful movie clip, the average valence rating should be negative. Since the average ratings of one of the amusing movie clips (Amusing 3 in Fig. 2) were negative, that clips' data were excluded from the final analysis of both the EDA responses and behavioural ratings. The reason for the negative value of this presumably positive valence movie clip is unknown, but it is clear that this clip showed larger rating variance than any other (Table 2). After excluding this movie clip, the valence ratings were averaged first for each movie clip and then for each movie type per each participant.

Valence rating ISC analysis. For each movie clip, we calculated the Pearson's correlations of the time courses of the dynamic valence ratings between subject *k* and each other participant within the corresponding group (control or dysphoric). After this, one ISC value for each movie clip from each participant was obtained by averaging the individual correlations. Then, the ISC was obtained by averaging the correlation coefficient values of each movie clip type for each participant.

Statistical analysis. All statistical analyses were conducted in IBM SPSS Statistics (Version 24, IBM Corporation, NY, USA).

The mean phasic EDA values, the average valence ratings, and the valence rating ISC for each movie type per each participant were analysed by using repeated measures ANOVA with Movie type (amusing vs. sad vs. fearful) as a within-subject factor and Group (control vs. dysphoric) as a between-subject factor, separately.

For the mean EDA values and the average valence ratings, whenever the main effect of Movie type emerged, paired samples t-tests with Bonferroni correction were conducted to compare the effect of each movie type. To investigate the possible effect of anxiety symptoms on the responses to Movie type, a separate analysis with DASS-A scores as a covariate was also performed by implementing an ANCOVA (Movie type × Group) for the whole group.

For the valence rating ISC, when an interaction effect (Movie type × Group) was statistically significant, comparisons based on independent t-tests were performed with a Bonferroni correction to investigate the difference in response to each movie type between the control and dysphoric groups. Repeated-measures ANOVAs and paired t-tests with Bonferroni corrections revealed the interaction effects within each group. To control for the possible effect of anxiety symptoms, a separate analysis with DASS-A scores as a covariate was also performed by implementing an ANCOVA for the dysphoric group. The effects of current medication status on valence ratings were explored by performing a repeated-measures ANCOVA with Medication (medicated vs. non-medicated) as a covariate for the dysphoric group.

Pearson's correlation coefficients (two-tailed) were computed separately for each movie type to examine the relationship between phasic EDA (mean phasic EDA values) and depression symptoms (BDI-II scores), behavioural evaluations (mean valence rating values) and depression symptoms (BDI-II scores), and valence rating ISC and depressive symptoms (BDI-II scores) in the dysphoric and control groups. For the whole sample, Spearman's rank correlation coefficients were calculated between the different measures, because the full sample's BDI scores were not normally distributed.

For all results, we reported 95% CIs based on bootstrapping with 1000 permutations. The threshold for statistical significance was $p<0.050$. Bonferroni-adjusted alpha levels less than 0.017 (0.050/3) were considered significant for *t*-tests investigating main or interaction effects. For the ANOVA results, *p*-values were reported based on the Greenhouse–Geisser correction, but the degrees of freedom were reported without correction. Partial eta-squared η_p^2 and Cohen's d were given for the estimated ANOVA and *t*-test effect sizes, respectively. Cohen's d was computed using pooled standard deviations[51]. Multiple correlations were controlled by applying a false discovery rate[57] of 0.05.

Ethical approval. This research follows the guidelines of ethical conduct and research reporting in accordance with the Declaration of Helsinki. The dataset (anonymous data including the main variables of the participants' background information, EDA and behavioural ratings) and code that were developed for the data analysis are available to the community upon reasonable request.

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Author contributions

X.L. and P.A. conceived the experiment; X.L., E.V. and C.Y. conducted the experiments; X.L. and Y.Z. analysed the data; and X.L., Y.Z. and P.A. drafted the manuscript. All authors revised and approved the manuscript.

Competing interests
The authors declare no competing interests.

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SUPPLEMENTARY MATERIALS

In the supplementary materials, the descriptive information of selected movie clips is presented in the Supplementary Table 1. The introduction to the plot of each movie clip is shown in the Supplementary Table 2.

Supplementary Table 1. Descriptive information of selected movie clips.

Movie	Emotion	Code	Length	Arousal scoringa	Description of the scene
City of angels	Sad	1	2'59''	5.15	Maggie dies in Seth's arms.
Dangerous mind	Sad	2	2'08''	5.25	Students in a school class are told that one of their classmates has died.
A perfect World	Sad	3	4'27''	5.78	Butch is gunned down, at the end of the movie.
The dead Poets Society (1)	Sad	4	3'51''	4.84	A schoolboy commits suicide.
Dead Man Walking	Sad	5	4'29''	5.87	The main character is put to death by lethal injection.
Les trois freres	Amusing	1	2'24''	4.36	One of the characters takes part in a TV game "the millionaire".
La cite de la peur	Amusing	2	2'13''	4.52	Three characters are at the dinner table and talk about the inquiry.
The visitors	Amusing	3	2'09''	3.55	Two men wearing medieval armors attack the postman's car.
When Harry met Sally	Amusing	4	2'45''	4.67	A female character fakes an orgasm in the restaurant, provoking Harry's embarrassment.
A fish called Wanda	Amusing	5	2'53''	4.04	The character gets undressed, waiting for his girlfriend. Unexpectedly, the owners of the house get into the house and discover him naked.
Le Pari	Amusing	6	1'47''	3.92	Lunch to celebrate father's birthday.
There is something about Mary (1)	Amusing	7	2'55''	4.02	Ted fights with a dog.
The Shining	Fear	1	4'15''	5.11	The character pursues his wife with an axe.
The Blair Witch Project	Fear	2	3'57''	4.95	Final scene in which the characters are apparently killed.
Scream 2	Fear	3	3'35''	4.81	A pursuit takes place in a school.
It	Fear	4	2'13''	4.69	A clown hidden in the sewer attracts a boy.
Copycat	Fear	5	2'23''	4.76	Monahan gets caught by a murderer in a toilet
Child's Play II	Fear	6	1'05''	4.63	Chucky beats Andy's teacher.

Note. The arousal scorings of the movie clips applied here were reported in Schaefer et al. (2010), which showed that the mean values of sad movie clips were the highest (by using a 7-piont scale, 1 = "no emotion at all", 7 = "very intensive emotion", sad: 5.478, amusing: 4.255, fearful: 4.825).

Supplementary Table 2. Introduction to the plot of each movie clip. The introduction was presented in Finnish in the measurement.

Movie	English	Finnish
City of angels	Seth and Maggie have finally been together. The next morning, as Seth is in the shower, Maggie rides her bicycle to a local store. On her way back, happy and fulfilled.	Seth ja Maggie ovat vihdoin olleet yhdessä. Seuraavana aamuna Sethin ollessa suihkussa, Maggie pyöräilee paikalliseen kauppaan. Paluumatkallaan, onnellisena ja tyytyväisenä …
Dangerous mind	Emilio is one of LouAnne's student. When LouAnne discovers that Emilio's life is in danger, she tries to protect him. She advises him to seek help from Principal Grandey. The next day, Emilio visits Grandey, but Grandey instantly dismisses him because he neglected to knock on Grandey's door before entering his office. Feeling rejected, Emilio leaves the school and is subsequently killed by his enemy.	Emilio on yksi LouAnnen oppilaista. Saadessaan selville, että Emilion elämä on vaarassa, yrittää LouAnne suojella häntä. LouAnne ohjaa Emilion rehtori Grandeyn puheille. Seuraavana aamuna Emilio käykin rehtorin työhuoneessa, mutta unohtaa koputtaa oveen ennen sisään astumistaan. Tämän vuoksi Grandey käännyttää hänet heti pois. Emilio poistuu koulusta koettuaan tulleensa hylätyksi ja joutuu myöhemmin vihollisensa murhaamaksi.
A perfect World	After escaping from a Huntsville prison, convict Butch and his partner Terry kidnap a young boy, Philip, and flee across Texas. As they travel together, Butch and Philip discover common bonds and suffer the abuses of the outside "Perfect World." In pursuit is Texas Ranger "Red" Garnett and criminologist Sally Gerber. Red's team surrounds the place where Phillip and Butch are situated, the latter sending the boy away to his mother, who is with Red's team.	Karattuaan Huntsvillen vankilasta, vanki Butch ja hänen seuralaisensa Terry kidnappaavat nuoren pojan, Philipin, ja pakenevat läpi Texasin. Yhdessä matkatessaan, Butch ja Philip huomaavat olevansa keskenään samanlaisia ja kärsivänsä ulkopuolisen, täydellisen maailman pahuudesta. Takaa-ajossa ovat osallisena Texasin ratsupoliisi ”Red” Garnett sekä kriminologi Sally Gerber. Redin tiimii saartaa alueen, jossa Philip ja Butch ovat. Lopulta Butch lähettää Philipin äitinsä luokse, joka on Redin tiimin mukana.

The dead Poets Society (1)	Neil Perry, although exceedingly bright and popular, is very much under the thumb of his overbearing father. Neil, along with their other friends, meets Professor Keating, their new English teacher, who tells them of the Dead Poets Society, and encourages them to go against the status quo. However, Neil is unable to find the courage to stand up to his father.	Neil Perry on erittäin fiksu ja suosittu, mutta myös hyvin paljon määräilevän isänsä tossun alla. Neil tapaa ystäviensä kanssa uuden englannin opettajansa, professori Keatingin, joka kertoo heille Kuolleiden runoilijoiden seurasta ja rohkaisee heitä vastustamaan nykyisiä olosuhteita. Neil ei kuitenkaan löydä tarpeeksi rohkeutta vastustaa isäänsä.
Dead Man Walking	Matthew Poncelet has been in prison for six years, awaiting his execution after being sentenced to death for killing a teenage couple.As the day of his execution comes closer, Poncelet asks Sister Helen, with whom he has corresponded, to help him with a final appeal. After many visits, she establishes a special relationship with him. Sister Helen's application for a pardon is declined. Poncelet asks Sister Helen to be his spiritual adviser through the day of execution, and she agrees.	Matthew Poncelet on ollut vankilassa kuusi vuotta. Hänet tuomittiin kuolemaan teinipariskunnan taposta ja nyt hän odottaa tuomionsa toteutumista. Kuolemantuomipäivän lähestyessä Poncelet pyytää kirjeystäväänsä, sisar Heleniä, auttamaan häntä viimeisen vetoomuksensa kanssa. Usean vierailukerran jälkeen, Helenin ja Ponceletin välille muodostuu erityinen suhde. Sisar Helenin vetoomus armahduksesta ei kuitenkaan mene läpi. Poncelet pyytää Heleniä hengelliseksi avuksi kuolemantuomiopäivänään ja Helen suostuu tähän.
Les trois freres	Three half-brothers are reunited at their mother's funeral. After being told of their inheritance they quickly spend the money, only to find out that they will not receive it after all. The brothers try to work out what to do and decide to participate in a TV game.	Kolme velipuolta tapaa toisensa pitkästä aikaa äitinsä hautajaisissa. Kuultuaan heille kuuluvasta perinnöstä kuluttavat he nopeasti perintörahansa, mutta kuulevatkin sitten, etteivät tulekaan saamaan perintöä. Veljekset miettivät, kuinka ratkaisisivat tilanteen ja päättävät osallistua TV-peliin.
La cite de la peur	Conversation between three characters at a dinner table.	Kolmen henkilön välinen keskustelu päivällispöydässä.
The visitors	A medieval nobleman and his squire are accidentally transported to contemporary times by a senile sorcerer.	Keskiaikainen aatelismies ja hänen aseenkantajansa siirtyvät vahingossa nykyaikaan vanhuudenhöperön velhon loihtimana.

When Harry met Sally	Harry and Sally have known each other for years, and are very good friends, but they fear sex would ruin the friendship. Harry and Sally are having dinner together.	Harry ja Sally ovat tunteneet toisensa vuosia ja ovat todella hyviä ystäviä, mutta pelkäävät, että seksi pilaisi heidän ystävyytensä. Harry ja Sally syövät päivällistä yhdessä.
A fish called Wanda	Sexy American diamonds lover Wanda and her boyfriend Otto are in England to plot alongside George and Ken the robbery of a diamond collection. Wanda and Otto want the stolen diamonds for themselves, and try to doublecross others for the loot. However, George has already moved the diamonds to another secret place. Wanda thinks the best way to find out is by getting close to George's lawyer - Archie. Now, Wanda and Archie are at house.	Viehättävä amerikkalainen timantteja rakastava Wanda suunnitteli timantti kokoelman ryöstön rikoskumppaneidensa kanssa. Hän kuitenkin tahtoo timantit kokonaan itselleen ja pyrkii varastamaan ryöstösaaliin myös kumppaneiltaan. George, yksi rikoskumppaneista, on siirtänyt timantit salaiseen paikkaan. Wanda ajattelee, että paras tapa selvittää timanttien olinpaikka on lähestyä Georgen asianajajaa Archieta. Nyt Wanda ja Archie ovat toisen kotona.
Le Pari	Bernard is a teacher in the suburbs and lives with Victoria. Didier is a wealthy Parisian pharmacist and is married to Murielle, Victoria's sister. While the former drives a rusty car, the latter drives a black Mercedes. Both brothers-in-law are complete opposites and hate each other. They are having a lunch to celebrate father’s birthday.	Bernard toimii opettajana lähiössä ja asuu yhdessä Victorian kanssa. Didier on varakas pariisilainen apteekkari ja on naimisissa Muriellan, Victorian sisaren, kanssa. Bernard ajaa ruosteisella autolla, kun taas Didierillä on musta Mercedes. He ovat toistensa vastakohtia ja vihaavat toisiaan, ja tässä he ovat juhlimassa appensa syntymäpäivää lounaalla.
There is something about Mary (1)	Ted gets a chance to meet up with his dream girl, Mary, from high school, even though his date with her back then was a complete disaster. Ted is having a conversation with Mary.	Ted saa mahdollisuuden tavata lukioaikaisen unelmien tyttönsä Maryn. Lukioaikana hänen treffinsä Maryn kanssa olivat täydellinen katastrofi. Ted keskustelee Maryn kanssa.
The Shining	A family heads to an isolated hotel for the winter where an evil and spiritual presence influences the father into violence, while his psychic son sees horrific forebodings from the past and of the future.	Perhe matkustaa eristyksissä olevaan hotelliin talveksi, jossa yliluonnollisen pahan läsnäolo saa perheen isän käyttäytymään väkivaltaisesti, samalla kun hänen meedio poikansa näkee kauhistuttavia pahoja enteitä menneestä ja tulevasta.

The Blair Witch Project	Three film students travel to a Maryland forest to film a documentary on the local Blair Witch legend	Kolme elokuva-alan opiskelijaa matkustavat Marylandin metsään tekemään dokumenttielokuvaa paikallisen noidan legendasta.
Scream 2	Two years after the events of Scream, Sidney Prescott and Randy are attending Windsor college. They are trying to get on with their lives.	Kaksi vuotta Screamin tapahtumien jälkeen Sidney Prescott ja Randy käyvät Windsorin yliopistoa ja yrittävät vain jatkaa elämäänsä.
It	In 1960, a group of social outcasts who are bullied by a gang of greasers led by Henry Bowers are also tormented by an evil demon who can shape-shift into a clown and feed on children's fears and kill them.	On vuosi 1960 ja hyljeksittyjen poikien ryhmää jota hätyyttää kiusaajien jengi Henry Bowersin johdolla, piinaa myös paha demoni, joka kykenee muuttamaan muotoaan pelleksi, saa voimansa lasten peloista ja pyrkii tappamaan heidät.
Copycat	Helen, an agoraphobic psychologist and M.J., a female detective work together to take down a serial killer who copies serial killers from the past. During the search for the serial killer, M.J. discovers that the killer has kidnapped Helen and taken her back to the restroom of the lecture hall. M.J. is getting there.	Helen, agorafobinen psykologi ja M.J., naisetsivä tekevät yhteistyötä saadakseen kiinni sarjamurhaajan, joka kopioi menneisyyden sarjamurhaajia. Murhaajan etsintöjen aikana M.J. huomaa murhaajan kaapanneen Helenin ja vieneen tämän takaisin luentosalin wc:hen. M.J. on matkalla Helenin luo.
Child's Play II	When Andy’s mother is handed over to a psychiatric hospital, the young boy is placed in foster care, as is the Chucky doll who is determined to take Andy’s soul. Chucky ends up on the bus to Andy’s school and Andy’s teacher finds the obscenities written by Chucky in this workbook. The teacher believes Andy is to blame for this and forces him to be left alone in the classroom as punishment and locks Chucky in the closet.	Kun Andyn äiti luovutetaan psykiatriseen sairaalaan joutuu nuori poika sijaishoitoon, samoin kuin Chucky nukke, joka on päättänyt vallata Andyn sielun. Chucky päätyy bussilla Andyn kouluun ja Andyn opettaja löytää tämän työvihkosta Chuckyn kirjoittamat rivoudet. Opettaja uskoo Andyn olevan tähän syyllinen ja pakottaa hänet jäämään yksin luokkahuoneeseen rangaistuksena ja lukitsee Chuckyn komeroon.

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III

EFFECT OF SAD MOOD ON AUTOMATIC CHANGE DETECTION OF FACIAL EXPRESSIONS – AN ERP STUDY

by

Xueqiao Li, Elisa Vuoriainen, Qianru Xu, & Piia Astikainen, 2022

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