Frontal EEG Asymmetry and skin conductance responses in lonely and non-lonely individuals to happy and neutral faces of another person

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ABSTRACT

Loneliness is an aversive signal that activates motivational, behavioral, and cognitive processes to resolve the negative emotions and outcomes it causes. The motivation to reaffiliate with others leads to seeking inclusive cues and approaching social stimuli. However, loneliness influences cognitive processes and may cause a negatively biased evaluation of social cues and lead to avoiding interaction instead. Facial expressions of another person are relevant social cues because they signal social intentions and emotions – the factors that influence the motivation to approach or avoid that person.

The present study investigated the psychophysiological responses of lonely and non-lonely individuals to the facial expressions of a happy and a neutral face. Skin conductance responses (SCRs) were examined to explain autonomic sympathetic arousal and frontal EEG alpha asymmetry to indicate motivational tendencies. These psychophysiological responses were expected to explain automatic reactions to social cues indicated by facial expressions, which lonely and non-lonely individuals may process differently.

Skin conductance responses were higher to a happy versus a neutral face for both groups. It demonstrates that reciprocal interaction with another person with a happy face elicits stronger autonomic arousal than a neutral face, which may indicate the intensity of a positively affected emotional-motivational response. The results showed that the SCRs were suppressed for lonely participants compared to non-lonely, reflecting the possible negative cognitive bias toward the social stimuli. However, the present study did not find influences of a happy versus a neutral face or modulating effects of loneliness on frontal alpha asymmetry. Further investigation is needed to determine whether facial expressions can modulate the frontal EEG alpha asymmetry of lonely and non-lonely individuals to show differences in their motivational tendencies.

Keywords: EEG asymmetry, skin conductance, loneliness, autonomic arousal, facial expression, social cognition, approach-avoidance motivation

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MATTILA, KATRI: Yksinäisten ja ei-yksinäisten frontaalisen EEG asymmetrian ja ihon sähkönjohtavuuden vasteet toisen henkilön iloisille ja neutraaleille kasvojen ilmeille

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Yksinäisyys on epämiellyttävä tila, jonka aiheuttamat negatiiviset tunteet aktivoivat yksilön motivationaalisia, käytöksellisiä ja kognitiivisia prosesseja. Yksinäisyys saa aikaan motivaation lähestyä uudelleen toisia ihmisiä, joka johtaa osallistavien vihjeiden etsimiseen ja sosiaalisten ärsykkeiden lähestymiseen. Toisaalta yksinäisyys vaikuttaa yksilön kognitiivisiin prosesseihin ja voi aiheuttaa negatiivista vinoumaa sosiaalisten vihjeiden tulkinnassa ja tätä kautta johtaa vuorovaikutuksen välttämiseen. Toisen henkilön kasvojen ilmeet ovat merkityksellisiä sosiaalisia vihjeitä, sillä ne viestivät sosiaalisista aikomuksista ja tunteista – tekijöistä, joiden havaitseminen vaikuttaa motivaatioon lähestyä tai välttää kyseistä henkilöä.

Tässä tutkimuksessa tutkittiin yksinäisten ja ei-yksinäisten tutkittavien psykofysiologisia reaktioita toisen henkilön iloiseen ja neutraaliin ilmeeseen. Autonomisen hermoston viriämisen vasteita mitattiin ihon sähkönjohtavuuden mittareilla ja motivationaalisia taipumuksia arvioitiin EEG asymmetrian avulla. Näiden psykofysiologisten vasteiden odotettiin selittävän tutkittavien automaattisia reaktioita kasvojen ilmeiden ilmaiseviin sosiaalisiin vihjeisiin, joita yksinäiset ja ei-yksinäiset henkilöt saattavat prosessoida eri tavoin.

Ihon sähkönjohtavuuden vasteet iloisiin kasvoihin olivat yksinäisillä sekä ei-yksinäisillä tutkittavilla korkeammat kuin neutraaleihin kasvoihin. Korkeampi autonominen viriäminen vastavuoroisessa vuorovaikutustilanteessa iloiseen verrattuna neutraaliin ilmeeseen voi ilmentää positiivisesti vaikuttavan emotionaalis-motivationaalisen vasteen voimakkuutta. Nämä vasteet olivat yksinäisillä vaimeampia ei-yksinäisiin verrattuna, joka heijastaa mahdollista negatiivista kognitiivista vinoumaa sosiaalisten ärsykkeiden tulkinnassa. Tässä tutkimuksessa ei havaittu iloisten ja neutraalien kasvojen ilmeiden tai yksinäisyyden vaikutusta frontaaliseen EEG alfa-asymmetriaan. Lisätutkimusta tarvitaan sen selvittämiseksi, voivatko kasvojen ilmeet moduloida yksinäisten ja ei-yksinäisten henkilöiden motivationaalisia taipumuksia EEG alfa-asymmetrialla mitattuna.

Avainsanat: EEG asymmetria, ihon sähkönjohtavuus, yksinäisyys, autonominen viriäminen, kasvojen ilmeet, sosiaalinen kognitio, lähestymis- ja välttämismotivaatio

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1. Introduction

1.1. Loneliness and social perception

Loneliness is a condition that affects many people at least at some point in their lives (Qualter, Vanhalst, Harris, Van Roekel, Lodder, Bangee, Maes & Verhagen, 2015). Individuals tend to experience loneliness when perceiving a deficiency in the quality or the number of their social relationships (Mund, Freuding, Möbius, Horn & Neyer, 2020; Spithoven, Bijttebier & Goossens, 2017). Experiences and trajectories of loneliness vary from chronic to transient phases in life (Vanhalst, Soenens, Luyckx, Van Petegem, Weeks & Asher, 2015), and prolonged experiences of loneliness, in particular, have been suggested to be associated with negative consequences for well-being and mental health (Qualter, Brown, Rotenberg, Vanhalst, Harris, Goossens, Bangee & Munn, 2013; Cacioppo, Grippo, London, Goossens & Cacioppo, 2015).

From an evolutionary perspective, just as hunger is an aversive signal to motivate individuals to eat, aversive signals caused by loneliness trigger motivational, behavioral, and cognitive processes to act to reduce its effects (Cacioppo, Hawkley, Ernst, Burleson, Berntson, Nouriani & Spiegel, 2006; Qualter et al., 2015). The experience of loneliness triggers the need for belonging and being socially included (Baumeister & Leary, 1995), and motivate lonely individuals to reconnect with others (Qualter et al., 2015; Cacioppo & Cacioppo, 2018). Therefore, loneliness can be described as a distressing emotional state, which prompts individuals to renew and maintain social contacts (Qualter et al., 2015; Spithoven et al., 2017). The motivation of lonely individuals to reconnect with others due to the experience of loneliness is often referred to as the motive for reaffiliation (Qualter et al., 2015). The evolutionary theory by Cacioppo & Cacioppo (2018) describes the lonely individual's motivation to approach social stimuli to repair or replace beneficial relationships for long-term evolutional fit.

On the other hand, loneliness has been associated with difficulties in processing social information and negative cognitive biases toward social cues (Strachman & Gable, 2006; Spithoven et al., 2017). Lonely individuals might perceive social stimuli as threatening and anticipate rejection, especially if the stimuli are neutral or vague (Spithoven et al., 2017). Fear of rejection may lead to avoidance to protect oneself from a negative outcome (Qualter et al., 2015; Spithoven et al., 2017). From an evolutionary perspective, loneliness can trigger avoidance of social threats as an evolutionary short-term survival promotion, leading to withdrawal from social situations (Qualter et al., 2015; Cacioppo & Cacioppo, 2018).

Just as differences in the processing of social information regulate individuals' motivation to either approach or avoid, these motivational tendencies also influence the evaluation of social cues (Strachman & Gable, 2006). For example, individuals with social avoidance goals have more negatively biased interpretations of social cues that are ambiguous (Strachman & Gable, 2006). Hence, lonely individuals' motivation to approach and their will to reaffiliate may trigger seeking inclusive cues, whereas their motivation to avoid may lead to a negative evaluation of social cues and withdrawal from the interaction. Loneliness has been associated with less approach motivation and an increased likelihood of having more avoidance-oriented goals (see Spithoven et al., 2017). Consequently, avoidance-oriented goals increase negatively biased interpretations and may increase loneliness (Strachman & Gable, 2006).

The processing of social cues appears to be a crucial process affecting lonely individuals' motivational tendencies. In social interaction, facial expressions of another person can be considered relevant social cues because they signal the social intentions and emotions of a person (e.g., Ekman, 1992), and affect an observer's motivation to approach or avoid that person (Adams & Kleck, 2003; Pönkänen & Hietanen, 2012). Seeing a happy face is likely to elicit positive emotions, autonomic sympathetic arousal, and trigger motivation to approach while seeing a neutral face may leave more room for different interpersonal evaluations (see Pönkänen & Hietanen, 2012). Neutral expressions of another person may be interpreted as expressing approach-related emotions when they are combined with a direct gaze (Adams & Kleck, 2003) and therefore, elicit positively affected emotional-motivational responses in the observer too. On the other hand, if the neutral face is perceived as ambiguous and does not imply social intent to the observer, it may attenuate the psychophysiological responses (see Pönkänen & Hietanen, 2012). Thus, seeing another person with a happy face is likely to elicit sympathetic autonomic arousal and motivation to approach, whereas seeing a person with a neutral face may either generate a smaller positively affected response or even a negatively affected response.

Rather than just perceiving a social signal, the affective psychophysiological responses to eye contact, for example, have been suggested to reflect the activation of self-referential processes due to the observation that the self is attended by another person, leading to reciprocal attention or interaction (Hietanen, 2018). According to this view, affective arousal or motivational tendencies may reflect these processes. These responses may also be suppressed due affective evaluation of the observer.

The present study investigates lonely and non-lonely individuals' motivational tendencies and autonomic sympathetic arousal when presented with social stimuli of happy faces and neutral faces. We are interested in whether loneliness generates differences in the psychophysiological responses following the facial stimuli, and hence, explains changes in the social information processing of lonely individuals. It has been suggested that the responses enhance by real faces and reciprocal interaction rather than, for example, by pictures (Hietanen, Leppänen, Peltola, Linna-Aho, & Ruuhiala, 2008; Pönkänen, Peltola & Hietanen, 2011; Hietanen & Hietanen, 2017). Therefore, in the present study, the facial expressions are presented by a live stimulus model.

1.2. Frontal Alpha Asymmetry as a measure of the motivational tendency

An individual's motivational tendency to approach or to avoid as a response to a situational stimulus or a social cue is regulated by the approach-avoidance motivational brain systems (Lang, Bradley & Cuthbert, 1990). Examining the activation of these systems is traditionally proceeded by measuring frontal cortical activity using an electroencephalogram (EEG) (see review by Harmon-Jones & Gable, 2018). The activity between the frontal cortical regions is often measured by comparing the volume of activation of the alpha band (8 – 13 Hz) in the left and right hemispheres (Harmon-Jones & Gable, 2018). The frontal alpha asymmetry value is obtained by subtracting left frontal alpha power from the right – a positive value refers to a relatively higher left-sided frontal activity, whereas a negative value refers to a relatively higher right-sided frontal activity (Harmon-Jones & Gable, 2018; Kiilavuori, Peltola, Sariola & Hietanen, 2022). Measuring the activity as a response to a given stimulus, relatively higher left frontal cortical activation has been linked to a tendency to approach and relatively higher right cortical activation to a tendency to avoid or withdraw (Hietanen et al., 2008; Harmon-Jones & Gable, 2018; Lauttia, Helminen, Leppänen, Yrttiaho, Eriksson, Hietanen & Kylliäinen, 2019).

The frontal EEG alpha asymmetry has been exploited in the research of social perception associated with the regulation of approach-avoidance motivation. Previous studies have shown strong evidence, that seeing another person with a direct versus averted gaze affect differently this regulation (e.g., Hietanen et al., 2008; Pönkänen et al., 2011). The EEG recordings have shown relatively more activation on the left hemisphere as a response to a direct gaze versus an averted gaze, indicating enhanced approach motivation. In addition, the effects occurred only with reciprocal interaction, which has been suggested to indicate the activation of the self-referential processing of the observer (Hietanen & Hietanen, 2017; Hietanen, 2018).

However, the effect of another person's facial expressions on the observer's approach-avoidance tendencies is less clear. A direct gaze and a smile both signal a motivational tendency to approach and, therefore, could potentiate relatively greater left cortical activation for the observer as well (Adams & Kleck, 2003). However, in the study of Pönkänen & Hietanen (2012), the results of EEG asymmetry measures did not show different activation in the neural systems of approach-avoidance motivation toward a direct vs. averted gaze, and the results did not show the effects of facial expression (low-intensity smile versus neutral face) either. The authors speculated there may be influences of individual traits or personal dispositions on frontal asymmetry.

The present study further investigates the effects of facial expressions on frontal EEG alpha asymmetry and examines the role of loneliness in the approach-avoidance motivation regulation. The aim is to examine whether happy and neutral expressions of live models modulate differences in alpha asymmetry (indicating motivational tendencies), and if so, whether they appear differently between lonely and non-lonely participants. To the author's best knowledge, the effect of another person's facial expressions on the motivational tendencies of lonely versus non-lonely individuals has not been studied in the EEG research of frontal alpha asymmetry.

1.3. Autonomic nervous system activity

Autonomic sympathetic arousal is associated with changes in heart rate, sweating, and blood pressure, which are linked to emotional and cognitive states (Critchley, 2002). Autonomic responses in the skin can act as social signals that help modulate interindividual interactions (e.g., Darwin, 1998). According to the review by Critchley (2002), the common factor that elicits autonomic arousal is the subjective salience of the signal, which is also related to motivational tendencies.

Examining the activation of the sympathetic nervous system, measuring the skin conductance responses (SCRs) has been shown to be a good index reflecting autonomic arousal (Andreassi, 2000; Critchley, 2002; Dawson, Schell & Filion, 2016). SCRs are measurable changes in the skin conductance at the surface (e.g., the palm of your hand), which reflect autonomic innervation of sweat glands to a transient event or stimuli (Critchley, 2002). While frontal EEG asymmetry indicates the direction of motivational tendencies (approach-avoidance), skin conduction levels indicate the intensity of the response (Lang et al., 1990; Hietanen et al., 2008; Pönkänen et al., 2011).

Like the frontal EEG alpha asymmetry, measurements of autonomic arousal have also been used in the research of psychophysiological responses to eye gaze and facial expressions. In the study of Martin & Gardner (1979), seeing a smiling face elicited higher autonomic arousal than a neutral face. In the study of Pönkänen & Hietanen (2012), seeing a person with a smile elicited a higher autonomic arousal response than seeing a person with a neutral face when measured with the SCRs. They also found that seeing a direct versus an averted gaze modulated higher autonomic arousal responses when combined with a smile. The authors speculated that a direct gaze and a smile are both salient signals of potential willingness for interaction.

Hietanen, Kylliäinen, and Peltola (2019) examined autonomic arousal responses (SCRs) to a smiling or neutral face of another person in two conditions: In the first condition, participants were told that another person saw them during the experiment, and in the second condition, they were told that the other person did not see them. Their results showed that the autonomic arousal response to a smiling face was greater than to a neutral face, but only when participants believed that the other person saw them. Therefore, the autonomic arousal responses to seeing another person's facial expressions appear to also require reciprocal interaction.

The present study investigates the effects of facial expressions on autonomic arousal by measuring skin conductance. The aim is to examine whether happy and neutral facial expressions of live models elicit changes in skin conductance (indicating the intensity of motivational tendencies) and, if so, whether SCRs differ between lonely and non-lonely participants. To the author's best knowledge, the effect of another person's facial expressions on the skin conductance levels of lonely versus non-lonely individuals has not been studied.

1.4. The present study

The present study examines the psychophysiological responses of lonely and non-lonely individuals to the facial expressions of a happy and a neutral face. These psychophysiological responses are expected to explain automatic reactions to social cues indicated by these facial expressions, which lonely and non-lonely individuals may process differently. The frontal EEG asymmetry is expected to indicate that the relative hemispheric activation that is associated with the direction of motivational tendencies (approach-avoidance) is activated by facial expressions. The skin conductance levels reflecting autonomic arousal are expected to indicate the intensity of the motivational response.

In measuring frontal alpha asymmetry, the aim is to examine a) how seeing another person's happy face versus a neutral face affects the motivational tendencies (approach versus avoidance) and b) how loneliness affects the direction and intensity of the motivational tendency. I assume that seeing another person's happy versus a neutral face elicits a relatively higher left frontal activation – reflecting participants' motivation to approach. I assume that the relatively higher left activation is more pronounced for lonely participants, due to their motivation to approach social stimuli that may promote connection with others.

Lonely individuals are more likely to perceive neutral or ambiguous social stimuli as threatening and endorse more avoidance-oriented dispositions (Strachman & Gable, 2006; Spithoven et al., 2017). Therefore, seeing a person with a neutral face might generate a more negatively affected evaluation, particularly for lonely participants. Hence, I assume that seeing another person with a neutral face elicits a relatively higher right frontal activation for the lonely participants – reflecting their motivation to avoid. In addition, I assume that non-lonely participants will vary in their regulated motivational tendencies and that the contrast between responses to happy and neutral faces is smaller for them than for lonely participants.

In measuring skin conductance, the aim is to examine a) how seeing another person's happy face versus a neutral face modulates autonomic arousal and b) how loneliness affects the intensity of the response. Seeing another person with a smile has been shown to elicit higher arousal than seeing a person with a neutral face (Martin & Gardner, 1979; Pönkänen & Hietanen, 2012; Hietanen, Kylliäinen, and Peltola, 2019). Therefore, I assume that seeing another person with a happy versus a neutral face elicits higher autonomic arousal for both lonely and non-lonely when measured with SCRs. I expect the intensity of the response to seeing another person's happy face to be higher for lonely participants due to their stronger motivation to approach social stimuli to reaffiliate. On the contrary, I assume the intensity of the response to seeing another person's neutral face is more attenuated for lonely individuals due to their possible negatively biased interpretation.

2. Methods

2.1. Participants

31 recruited adults (mean age = 30.26 years, range = 19 – 49 years, SD = 8.15) participated in the study. The participants were mostly right-handed (n = 29), one left-handed, and one ambidextrous. All the participants signed a written informed consent and received two movie tickets for their participation. Participants were allowed to discontinue at any point of the examination. The study protocol was approved by the Ethics Committee of the Tampere region.

Volunteers for the study were pre-interviewed to ensure fitting in the participation criteria. Participation criteria were changed during the data collection because only a few volunteered to participate with the original criteria. The exclusion criteria for the first 23 participants were the following: neurological conditions (migraine or learning disabilities were allowed), drug or alcohol abuse, heart disease or a pacemaker, significant mobility impairment, non-Finnish speaker, a medication that affects the central nervous system, vision or hearing impairment (unless corrected to normal), pregnancy or on lactation period, or being in a high-risk group for covid. One participant was allowed to participate despite the central nervous system affecting medication.

For the first 23 participants, the inclusion criteria for lonely individuals (n = 10) included the experience of loneliness evaluated either *quite often* or *very often* and having no psychotic disorders or ongoing psychiatric disorders. Previous depression or anxiety disorders were allowed if they had not been active the past year, as well as personality disorders or eating disorders. The inclusion criteria for the non-lonely group (n = 13) included the experience of loneliness evaluated as *none* or *sometimes* and having no background of psychotic or psychiatric disorders.

The participation criteria were changed for the remaining 8 participants (lonely = 4, non-lonely = 4) because of the challenges of meeting the inclusion criteria. The inclusion criteria of no background of psychotic or psychiatric disorders for the non-lonely group were changed to match the lonely individuals' inclusion criteria – the former psychiatric disorder was allowed for all the participants. A medication that affects the central nervous system was allowed if a participant was without it for 24 hours before the examination. In addition, the evaluation of the current experience of loneliness (scale *none – sometimes – quite often – very often*) was not the participation criteria anymore. The division of the participants into lonely and non-lonely was decided to reimplement based on their scores on the loneliness questionnaire (UCLA-12; Junttila, Ahlqvist-Björkroth, Aromaa, Rautava, Piha, Vauras, Lagström & Räihä, 2013).

2.2. Questionnaires

The participants were asked to fill out a Finnish shortened version of the UCLA Loneliness Scale (Junttila et al., 2013; original by Russell, Peplau & Cutrona, 1980). The shortened 12-item scale includes 6 items on social loneliness and 6 items on emotional loneliness. The participants were asked to evaluate how often they feel the way the items state on a scale of 1 – 4 (1 = *never* – 2 = *rarely* – 3 = *sometimes* – 4 = *often*). The score range was 13 – 48. The score dividing participants into lonely and non-lonely was based on the mean split score (non-lonely < mean split < lonely).

The participants were asked to fill out the Finnish version (2020) of the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977; Finnish translation by Kivinen, Heikkinen & Äystö, 1998; Finnish translation modified by TOIMIA, 2020) which was shortened to 10 items. The short version followed the shortened CES-D Scale by Andersen, Malmgren, Carter & Patrick (1994). In addition, the participants filled out Finnish translations (TOIMIA, 2020) of the Psychometric Properties of the Social Phobia Inventory Scale (SPIN; Connor et al., 2000), Social Provision Scale (SPS; Cutrona & Russel, 1987) and State-Trait Anxiety Inventory (STAI-Y2; Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983). The aim was to examine whether the lonely and non-lonely participants' test scores differ on these factors.

On the 10-item CES-D questionnaire, the participants evaluated their experiences on a scale from 0 – 3 (0 = *rarely or never* – 1 = *sometimes* – 2 = *quite often* – 3 = *often)*. Scores of ≥ 10 imply depression. On the 17-item SPIN questionnaire, participants evaluated their experiences of social phobia on a scale from 0 – 4 (0 = *not at all* – 1 = *a little bit* – 2 = *somewhat*

– 3 = *very much* – 4 = *extremely*). Scores of 21 – 30 indicate mild social phobia, 31 – 40 moderate social phobia, and 41 – 50 severe social phobia. On the 20-item STAI-Y2 questionnaire, participants evaluated their general anxiety feelings on a scale from 1 – 4 (1 = *almost never* – 2 = *sometimes* – 3 = *often* – 4 = *almost always*). Higher scores indicate higher general anxiety. On the 24-item SPS questionnaire, participants evaluated their provisions of social relationships (*attachment, social integration, reassurance of worth, reliable alliance, guidance, opportunity for nurturance*) on a scale from 1 – 4 (1 = *strongly disagree* – 2 = *disagree* – 3 = *agree* – 4 = *strongly agree*). Higher total social provision scores indicate greater levels of social provisions. The descriptive statistics are presented in **Table 1**.

Table 1. Descriptive Statistics: Demographic information comparisons between the groups

	Lonely	*Non-lonely*	*Total*
Data 1: EEG Asymmetry			
Number	12	13	25
Female	5	10	15
Male	7	3	10
Mean age (SD)	34.08 (2.76)	28.39 (1.68)	31.12 (8.29)
Mean UCLA-12 (SD)	30.25*** (3.84)	16.92 (3.30)	23.32 (7.64)
Mean CES-D-10 (SD)	12.25** (4.90)	5.8 (3.67)	
Mean SPIN-17 (SD)	19.17** (7.03)	9.00 (8.51)	
Mean SPS-24 (SD)	69.58*** (7.95)	88.53 (4.05)	
Mean STAI-Y2 (SD)	49.50*** (8.42)	32.00 (6.76)	
Data 2: Skin Conductance			
Number	14	11	25
Female	6	7	13
Male	8	4	12
Mean age (SD)	32.86* (2.17)	25.64 (1.66)	29.68 (7.85)
Mean UCLA-12 (SD)	31.07*** (1.01)	17.46 (0.81)	25.08 (7.64)
Mean CES-D-10 (SD)	11.36** (4.92)	5.36 (2.34)	
Mean SPIN-17 (SD)	19.29** (7.87)	8.18 (7.37)	
Mean SPS-24 (SD)	69.43*** (8.15)	86.18 (4.17)	
Mean STAI-Y2 (SD)	48.29*** (8.12)	30.64 (5.82)	

The final group subdivision and statistical analyses were performed separately for the EEG and skin conductance data sets. The participants are from the same original sample and thus partly the same in both data sets.
The table reports the two-way independent t-test results of significant differences between groups.
* p < .05; ** p < .01; *** p < .001.

2.3. Experimental procedure

In the experiment, participants were presented with two facial expressions as stimuli: a happy face and a neutral face. The face was displayed by an assistant (stimulus model) who was instructed to present the happy face as a big genuine smile without showing teeth. In the neutral face, instructions were to keep a slight tension in the cheek muscles so that the expression would not look negative. The stimulus was presented through a smart glass switching from transparent to opaque. The transparency of the smart glass was controlled by the researcher using presentation software (Neurobehavioral Systems, Inc., Berkeley, CA, United States).

The order of stimuli was randomized, and the presented stimulus was designated by a red (happy face) or blue (neutral face) led light on the assistant's side of the smart glass. The light signal was first given 15 – 40 seconds before the presentation and again 5 seconds before the glass switched to transparent. The face was presented through a transparent glass for 5 seconds and the glass was turned back to opaque before the next trial. The researcher controlled the start time of the next trial, which began 15 – 40 seconds after the previous trial when the participants' skin conductance had stabilized. There was a total of 20 trials, including 10 of each facial expression.

The assistants and their instructions for presenting facial expressions were unknown to the participants. In the beginning, participants were told that another person would sit on the other side of the smart glass during the experiment. Participants were instructed to look toward the glass when it was opaque and to the face or the eyes of the other person when it was transparent. The participant and the stimulus model were advised to avoid excessive movement and not to conversate during the experiment. The experiment involved both female and male dyads as the participant and the assisting model.

2.4. Data analysis

In the present study, EEG and SCR were measured during the experiment. The following data analyses followed the analyzing process of Kiilavuori, Peltola, Sariola & Hietanen (2022) in their respective experiment setting.

Frontal EEG Asymmetry. EEG was recorded with a NeurOne amplifier (NeurOne Bittium Biosignals, Ltd., Kuopio, Finland) using a 128-channel HydroGel Geodisc sensor network (Electrical Geodesic Inc, Eugene, Oregon). During the EEG signals were referenced to the Cz electrode. In the data analysis, it was switched to the average reference of all the electrodes. The EEG was examined during a 5-second facial stimulus presentation trial to assess asymmetry. Each 5 s trial for each facial stimulus was segmented into nine 1 s epochs with 0.5 s overlap, which makes a total of 9 segments per trial. To meet the criteria for calculating average asymmetry, a minimum of 5 segments per trial was needed to ensure reliability.

The EEG signal was filtered with a 0.1 – 30 Hz cut and a 50 Hz notch filter. Vertical eye movements were ocular-corrected using channel 8 (VEOG). Channel 1 (HEOG) was used to correct lateral eye movements for data from two participants. Raw data inspection was used to detect unusable or bad channels due to signal noise or poorly connected electrodes. Bad channels with ≥ 20 % artifact rates were interpolated. If the data included ≥ 50 % trials that did not meet the criteria of 5 usable segments, channels with an artifact rate of less than 20 % (if they differed from the others) were interpolated to enhance the data. In the procedure, each facial stimulus was presented 10 times, which makes a total number of 10 trials (with 9 segments) for each EEG channel. Subsequent asymmetry analyses required a minimum of 50 % trials per facial stimulus to ensure reliability, or the data were excluded. EEG data from six participants were excluded from the final analyses due to the low number of usable trials.

Fast Fourier Transformation (FFT) was used to calculate the power spectra for all bands, including the 8 – 13 Hz alpha band. Alpha band's power values were averaged for each channel over the included trials. Due to the right-skewed distribution of the values, a natural log transformation was calculated. Finally, asymmetry scores for both facial stimulus conditions were calculated for the frontal F4/F3 electrode pair. The asymmetry score was obtained by subtracting the power value of channel 24 (F3) of the left hemisphere electrode site from the power value of channel 124 (F4) of the right site (see Kiilavuori et al., 2022).

Skin conductance. Measuring the skin conductance responses, two disposable isotonic Ag/AgCl electrodes (EL507, Biopac Systems, INC) were attached to the non-dominant hand of the subject. One in the thenar eminence on the palm and the other hypothenar eminence on the palm. SCR measures changes in the skin conductance on the palm surface, reflecting autonomic innervation of sweat glands (see Critchley, 2002) to facial stimuli.

In the data analysis, the 1000 Hz frequency of the SCR channel was changed to 100 Hz to reduce the sampling frequency. The data was filtered with a 10 Hz high cut-off to exclude frequencies above the slow-wave SCR from the analysis. The SCRs were calculated by subtracting the minimum skin conductance change from the maximum change after stimulus onset. The minimum change was detected within 900 – 5000 ms after the stimulus onset and the maximum change within 900 – 10000 ms. If there was more than one peak in the maximum change window, the SCR was calculated from the first occurring one. A change of at least 0.01 µS within the time frame was detected as a response. If the change was less than 0.01 µS or the change was decreasing without a peak, it was coded as a zero response. If the increasing change occurred too early (within 0 – 900 s), the trial was excluded from the analyses. Subsequent analyses required a minimum of 50 % usable trials, including at least two non-zero responses per facial stimulus, or the data were excluded. SCR data from six participants were excluded from the final analyses because the number of zero responses was too high.

Finally, the skin conductance response scores (including the possible zero responses if the trial included at least two non-zero ones) for both facial stimulus conditions were calculated as the average score for each participant. Due to the right-skewed distribution of the values, a log10 (SCR + 1) transformation was calculated (see Kiilavuori et al., 2022). The log10 (SCR + 1) transformation was not sufficient to normalize the distribution of the lonely group.

2.5. Statistical analyses

The following statistical analyses were performed separately for the EEG and skin conductance data sets. Data from an individual participant may have been included in the

EEG analysis but not in the skin conductance analysis or vice versa, depending on whether the participant’s measurements were accepted in the final sample after the data analysis.

Frontal EEG Asymmetry. The final EEG asymmetry analyses included data from 25 participants. The UCLA-12 scores of included participants were averaged (*M* = 23.32) and used as a mean split threshold to divide the participants into the lonely (*n* = 12) and non-lonely group (*n* = 13). An independent samples t-test was performed to examine comparisons between groups in terms of age and questionnaire scores (**Table 1**). A repeated measures ANOVA was conducted for the ln-transformed asymmetry scores with facial stimulus condition (happy and neutral face) as a within-subject factor and group (lonely and non-lonely) as a between-subject factor. Two-sided tests were used to determine the significance of the results.

Skin conductance. The final skin conductance analyses included data from 25 participants. The UCLA-12 scores of included participants were averaged (*M* = 25.08) and used as a mean split threshold to divide the participants into the lonely (*n* = 14) and non-lonely group (*n* = 11). An independent samples t-test was performed to examine comparisons between groups in terms of age and questionnaire scores (**Table 1**). A repeated measures ANOVA was conducted for the log10 (SCR +1) scores with facial stimulus condition (happy and neutral face) as a within-subject factor and group (lonely and non-lonely) as a between-subject factor. Two-sided tests were used to determine the significance of the results.

3. Results

3.1. Frontal EEG Asymmetry

The ANOVA results of the EEG Asymmetry scores with facial stimulus condition (happy vs. neutral) as a within-subject and group (lonely vs. non-lonely) as a between-subject are shown in **Figure 1**. The results showed no significant main (condition *F* (1,23) = 0.105 *p* = .748; group *F* (1,23) = 0.048 *p* = .828, *η2p* = 0.005) or interaction effects (*F* (1,23) = 1.654 *p* = .211, *η2p* = 0.067). Both faces elicited a relatively higher right frontal activation in both groups, which was shown as negative asymmetry scores in the happy face stimulus condition (lonely *M* = -0.087 *SD* = 0.499; non-lonely *M* = -0.103 *SD* = 0.391) and the neutral face stimulus condition (lonely *M* = -0.059 *SD* = 0.473; non-lonely *M* = -0.120 *SD* = 0.401). However, the values did not differ statistically from zero either in the happy face (lonely *t* = -0.603 *df* = 11 *p* = .559 *CI* [-0.404; 0.230]; non-lonely *t* = -0.948 *df* = 12 *p* = .362 *CI* [-0.339; 0.133]) or in the neutral face condition (lonely *t* = -0.429 *df* = 11 *p* = .676 *CI* [-0.359; 0.242]; non-lonely *t* = -1.077 *df* = 12 *p* = .303 *CI* [-0.362; 0.122]).

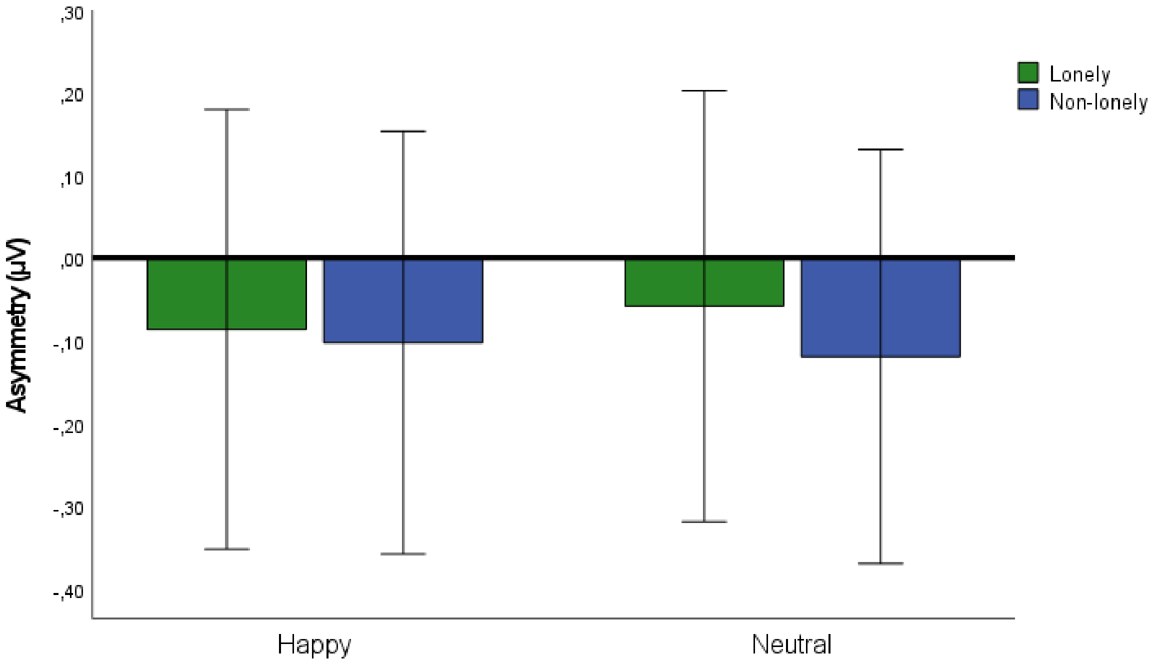
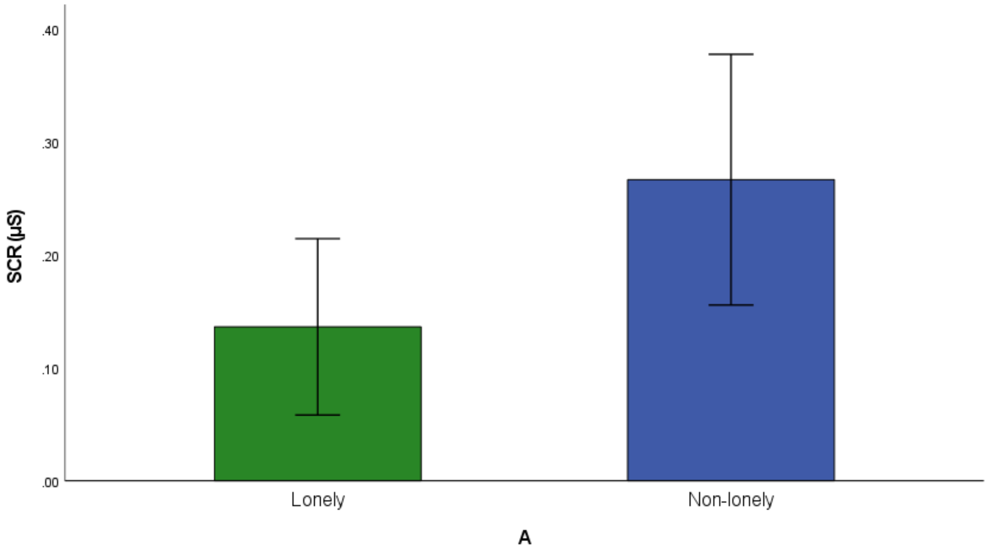


Figure 1. Mean ln-transformed Frontal EEG Asymmetry amplitude (µV) scores with a 95 % confidence interval. The scores did not differ significantly within conditions or between groups.

3.2. Skin Conductance Responses

The ANOVA results of the skin conductance scores with facial stimulus condition (happy vs. neutral) as a within-subject and group (lonely vs. non-lonely) as a between-subject are shown in **Figure 2**. The results showed a significant effect of facial expression (*F* (1, 23) = 10.424, *p* = .004, *η2p* = 0.312) and a main effect of the group (*F* (1,23) = 4.713, *p* = .040, *η2p* = 0.170), but no interaction effect (*F* (1, 23) = 0.165, *p* = .688, *η2p* = 0.007). The SCRs were higher for non-lonely participants (lonely *M* = 0.136 *SD* = 0.135; non-lonely *M* = 0.266 *SD* = 0.165) and higher when seeing a happy versus a neutral face (happy *M* = 0.214 *SD* = 0.176; neutral *M* = 0.173 *SD* = 0.149).



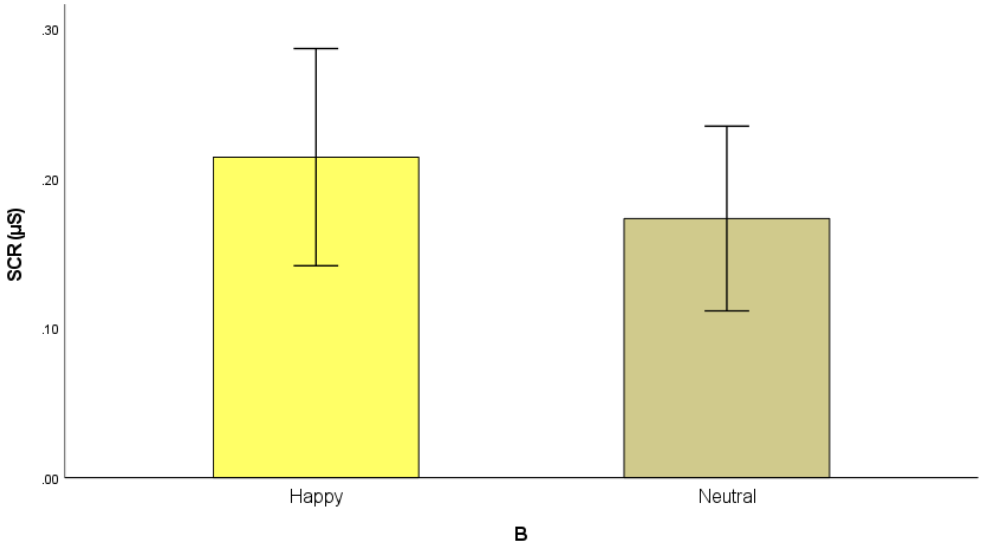


Figure 2. Mean log10 (SCR+1) -transformed Skin conductance amplitude (µS) scores with **A)** a main effect of the group and **B)** a main effect of the facial stimulus condition.

4. Discussion

The present study examined frontal EEG alpha asymmetry and autonomic arousal responses of lonely and non-lonely individuals to another person's facial expressions of a happy and a neutral face. The aim was to investigate whether happy and neutral expressions of live models modulate differences in alpha asymmetry (indicating motivational tendencies) and skin conductance levels (indicating the intensity of motivational tendencies), and how the responses differ between lonely and non-lonely participants.

We found that the autonomic arousal measured with skin conductance responses was modulated by facial expressions of a happy and a neutral face. The results replicated the findings (Pönkänen & Hietanen, 2012; Hietanen, Kylliäinen, and Peltola, 2019) of higher SCRs to another person's smiling versus neutral faces in a live setting with the reciprocal connection. Interestingly, the responses elicited higher for non-lonely participants than for lonely participants in both face conditions. The partial eta squared indicated a large effect for both expression and the group. The results indicate that facial expression modulates differences in skin conductance in the same direction in both groups, but the responses are more attenuated for the lonely participants regardless of the expression.

We hypothesized that the intensity of the SCRs to another person's happy face could elicit higher for lonely participants due to their stronger motivation to approach social stimuli to reaffiliate. However, there was no interaction effect between the face condition and the group: the intensity of the motivational or affective response was higher for non-lonely individuals in both expressions. The result may reflect lonely individuals' negative cognitive bias toward social stimuli (Spithoven et al., 2017). On the other hand, the happy face stimulus may have also been regarded as ambiguous or not reflecting a real social intention rather than a signal of the inclusive cue of reaffiliation. Therefore, it may not have elicited lonely participants' greater desire to approach. According to the review of Spithoven et al. (2017), the experience of loneliness may affect the social information perception in the way that the neutral or ambiguous stimulus is perceived as threatening. The present study supports the view with the results of lonely participants' attenuated SCRs to a neutral face stimulus compared to non-lonely participants.

In the present study, the frontal EEG alpha asymmetry measures did not show the effects of facial expressions of a happy and a neutral face. The outcome is in line with the findings (Pönkänen & Hietanen, 2012) of frontal alpha asymmetry not showing relatively unilateral hemispheric activation to facial expressions that could have indicated differences in the direction of approach-avoidance motivation. The present study also did not find a group effect between lonely and non-lonely individuals.

The results were contrary to expectations that seeing another person’s happy versus a neutral face would elicit a relatively higher left frontal alpha activation and reflect participants’ motivation to approach – and that it would be more pronounced for lonely participants. It was also hypothesized that the neutral face would elicit lonely participants’ relatively higher right frontal alpha activation and reflect their motivation to avoid, whereas non-lonely participants would vary in their regulated motivational tendencies. Numerically, both groups obtained negative asymmetry scores for both facial stimulus conditions, but they did not differ statistically from zero, and the confidence intervals of the scores were wide in both directions.

It remains unclear whether facial expressions can modulate the frontal EEG alpha asymmetry of lonely and non-lonely individuals and indicate differences in their motivational tendencies. One possibility is that because both a happy and a neutral face are typical and most-seen facial expressions in daily life, they do not evoke approach-avoidance tendencies in the experimental setting with no interaction. The participants did not have a chance to interact with the assistants prior to the experiment either, which may have affected the results. It is possible that participants would have needed more social interaction or connection to the person behind the smart glass to form approach-avoidance goals.

In addition, the lab context in which the neural responses were measured is a rather unnatural situation. Therefore, the individual differences in response to the experimental procedure may have caused inconsistent results. However, the presented facial expressions did influence autonomic responses in the same context. The validity of frontal EEG asymmetry as a measure has been questioned due to its sensitivity to other situational variables or state influences (see Harmon-Jones & Gable, 2018; Kiilavuori et al., 2022), which may explain the inconsistent results between psychophysiological responses. In addition, the facial expressions were presented 10x10 times, which may have caused habituation to the stimulus. Because of these factors, the phenomenon may have remained hidden.

The relatively small sample size limits the reliability of the results. In both data sets, the final analyses included only 25 participants divided into groups of lonely and non-lonely participants. Although the groups differed significantly in their UCLA-12 scores, the results of psychophysiological responses would have been more reliable with a larger sample to explain the differences between lonely and non-lonely individuals. Moreover, the log10 (SCR + 1) transformation was insufficient to normalize the distribution of the lonely group in the skin conductance sample. Thus, the parametric ANOVA may not have provided fully reliable results.

In addition, the effect of other individual trait factors together with loneliness requires further investigation. In the present study, the lonely participants differed from the non-lonely participants in their scores on depression, social phobia, provisions of social relationships, and general anxiety. The average scores of lonely participants implied depression and mild social phobia. They also scored higher on their general anxiety and evaluated lower levels of social provisions. Further research is required to speculate the effect of these factors on loneliness and psychophysiological responses.

In conclusion, the present study showed that another person’s facial expression can modulate the autonomic arousal responses of the observer in a live reciprocal interaction. In addition, the results demonstrated that the responses were attenuated for lonely individuals when compared with non-lonely individuals, which indicates differences in the processing of social information. Further research is needed to determine whether facial expressions can modulate the frontal EEG alpha asymmetry and show the effect of loneliness on motivational tendencies.

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