Neural responses to facial expressions: A story of arousal and valence?

by

Amie Jeannette Durston

A thesis

presented to the University Of Waterloo

in fulfilment of the

thesis requirement for the degree of

Master of Arts

in

Psychology

Waterloo, Ontario, Canada, 2024

© Amie Jeannette Durston 2024

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

Facial expressions of emotion provide important information about our social partner's internal state. Historically facial expressions have been conceptualized as discrete categories (i.e., happy, angry), as well as along a continuum of arousal (activated to calm) and valence (positive to negative). Both behavioural and event-related potential (ERP) research attribute emotion category effects (i.e., happy vs angry) to arousal and valence, however, no study has directly linked these constructs. The aim of the present study was to understand if early ERP components involved in visually processing facial expressions are sensitive to these continuous factors (i.e., arousal and valence) at the stimulus level. ERPs were recorded while 80 participants viewed faces expressing fear, anger, happiness, and no emotion, and performed a gender discrimination task. Following the ERP task, participants then viewed each face again and rated them on arousal and valence using 1-9 Likert scales. Individual ratings from each face were linked back to ERP data, trial by trial. ERPs were analyzed in a data-driven way (all time points, all electrodes) using mass univariate statistics. Paired contrast between expressions were analyzed using three different hierarchical models: without (original) and with valence or arousal ratings. Results from models with ratings highly overlapped with the original model, although were more restricted. The N170 component was the most impacted by arousal and valence ratings, where most emotion contrasts revealed significant valence or arousal interactions at this peak. On the P2 emotion differences were driven by more negative amplitudes for angry than happy or neutral faces, but this was unrelated to any rating. On the Early posterior negativity (EPN) happy faces elicited more negative amplitudes than fearful and neutral faces, a difference related to both arousal and valence ratings. However, no other contrast was significant on the EPN. Overall, our analyses show that ERP emotion effects are related to the participants' perceived arousal and valence of the stimuli, although these relationships highly depend on the specific contrast analyzed. We conclude that perceived arousal and valence of individual stimuli is a critical source of ERP variability, likely contributing to inconsistent findings in the field. Future research must consider the relationship between stimuli ratings and ERP amplitudes to fully unpack how and when our brain extracts emotional information from faces.

Acknowledgements

First, I thank my phenomenal supervisor, Dr. Roxane Itier. Back in 2019 when you took me on as a co-op student, I only could have dreamed that you and I would be here today finalizing this thesis and preparing for my PhD. Yet, here we are, and I couldn't be more grateful. Thank you for always pushing me to my fullest potential and showing me what honest and well-done science looks like. Thank you for genuinely caring about how I am doing outside of academia and encouraging me to take breaks when I need them. I would not be the academic I am today without you.

I would also like to thank Dr. Mike Dixon and Dr. Clara Colombatto for taking the time to read this thesis and give insightful feedback and edits. Thank you both for being engaged with my research to-date.

A huge thank you to my friends and family, you mean the world to me. To my friends in my lab (Zora, Seth, Alexandra) and other labs (Kristina, Krista, Julianna) - research is hard, but it is easier with people who understand by your side, so thank you. To my parents (Karen and Roger), partner (Ray), and closest friends (Kaitlyn, Aryn, Natasha, Miranda) - thank you for always encouraging me to shoot for the stars, and being there when things get hard. I love you all.

Lastly, this research project would not have been possible without the NSERC funding awarded to Dr. Itier, and the scholarships I received from NSERC and OGS. I further want to express my gratitude to every UW student who sat through this three-hour long study….. you are the real MVPs of this work.

Table of Contents

Author's Declaration ii
Abstract iii
Acknowledgements iv
List of Figures vi
List of Tables vii
Chapter 1 Introduction 1
Chapter 2 Methods 6
2.1 Participants 6
2.2 Stimuli 6
2.3 Procedure 7
2.4 Eye Tracking and EEG Acquisition 8
2.5 Data Processing 9
2.6 Data Analysis 9
Chapter 3 Results 12
3.1 Arousal and Valence Ratings 12
3.2 ERP analyses 15
3.2.1 Main Effects 15
3.2.2 Neutral-happy expression contrasts 16
3.2.3 Neutral-angry expression contrasts 18
3.2.4 Neutral-fearful expression contrasts 20
3.2.5 Happy-angry expression contrasts 22
3.2.6 Happy-fearful expression contrasts 24
3.2.7 Angry-fearful expression contrasts 26
Chapter 4 Discussion 28
References 35
Appendix A Circumplex Figure 45
Appendix B Detailed Result Tables 46
Appendix C Exploratory Regression Results 52

List of Figures

Figure 1 Visual depiction of the task and trial progression in the study. 8
Figure 2 Visual displays of mean arousal and valence ratings, for each participant, for each emotion..... 14
Figure 3 Main effects of emotion as revealed by original (emotion), arousal, and valence analyses *(p<.05)*. 16
Figure 4 Results from the neutral and happy expression contrasts (*p*<.008). 17
Figure 5 Results from the neutral and angry expression contrasts (*p*<.008). 19
Figure 6 Results from the neutral and fearful expression contrasts (*p*<.008). 21
Figure 7 Results from the happy and angry expression contrasts (*p*<.008). 23
Figure 8 Results from the happy and fearful expression contrasts (*p*<.008)..... 25
Figure 9 Results from the angry and fearful expression contrasts (*p*<.008). 26

List of Tables

Table 1 Means and standard deviations for arousal and valence ratings of each expression. 13

Chapter 1
Introduction

Facial expressions are a critical source of information in social interactions, providing details about social partners' inner states (Keltner et al., 2019; Van Kleef, 2009, 2010). Emotions and their respective expressions have been conceptualized through two lenses. First, as discrete categories, involving emotion-specific facial movements and biological states (Ekman, 1993; James, 1884). Second, as a continuum of emotional qualities, including valence [positive-negative] and arousal [calm-activated] (Russell, 1980; Russell & Bullock, 1985). These two theories overlap, as emotion categories are typically grouped based on these dimensions. For example, fear and anger are traditionally negative and high on arousal, whereas happiness is traditionally positive and high on arousal. Further, when categories are plotted on this continuum, they form a circle coined the circumplex (Russell, 1980, 2003; Appendix A Figure 1). Expression categories encompass a large amount of variation in expression structure and internal experiences (Ekman, 1965, 1993; Tracy & Robins, 2007). Think about all the different ways one can express or experience happiness; it can exist in many states (e.g., open or closed smiles, wide or neutral eyes, high or low arousal, contentment or elation). Yet, these nuances are rarely given attention in face perception research, where all trials related to a predefined expression category are averaged. This approach overlooks the unique stimulus-level variation in neural and behavioural responses to expressions within the same emotion category. These variations may lead to differences in behaviour (Adolph & Alpers, 2010) and neural responses (Calvo, Marrero, et al., 2013) and should be accounted for to ensure generalizable and well-informed results. To address this gap, the present study considered behavioural and neural responses to facial expressions through categorical and continuous lenses at the stimulus level to fully understand how we perceive and decode these expressions. Overall, the present study investigates whether early ERP components involved in visually processing facial expressions are sensitive to these continuous factors (i.e., arousal and valence) at the stimulus level.

Previous literature has investigated arousal and valence ratings of facial expression categories (i.e., averaged trials based on the emotion label, e.g. "happy"). Neutral expressions are consistently rated as the least aroused and the most neutrally valenced expression (Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Calvo et al., 2016; Herbert et al., 2013; Schupp, Ohman, et al., 2004; Smith et al., 2013). Happy faces are often rated similarly on arousal as threat-related expressions such as fear and anger (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Herbert et al., 2013; Smith et al., 2013; Sutton et al., 2019), but some find happy faces rated as either higher (Goeleven et al., 2008) or lower (Schupp, Ohman, et al., 2004) on arousal. Happy faces are always the

most positively rated on valence compared to all other emotions (Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Calvo et al., 2016; Herbert et al., 2013; Schupp, Ohman, et al., 2004; Smith et al., 2013). Fearful expressions are often rated as lower on arousal than angry and happy ones (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013), although sometimes fearful and angry expressions do not differ in arousal ratings (Goeleven et al., 2008; Herbert et al., 2013; Smith et al., 2013; Sutton et al., 2019). Some find angry faces more negatively valenced than fearful faces (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013), whereas others find no difference between these expressions (Herbert et al., 2013; Smith et al., 2013). As is evident by the overview of research presented above, there are inconsistencies when comparing ratings between happy, angry, and fearful expressions, but in all studies the ratings align with the circumplex model, at least to some extent (Russell, 1980, 2003; Appendix A Figure 1).

Critically, arousal and valence ratings of facial expressions have been collected using different prompts, potentially leading to some inconsistencies. Many studies use wording such as "how positive or negative is this expression" for valence and "how emotionally arousing is this expression" for arousal (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Eisenbarth & Alpers, 2011). Others use the affective mannikins developed by Bradley and Lang (1994). Importantly, although not all studies report their wording used in conjunction with the manikins (Herbert et al., 2013; Schupp, Ohman, et al., 2004), one study asked participants to match the facial expression to the manikins (Goeleven et al., 2008). Thus, inconsistencies in the conceptualization and operationalization of these ratings may be a large source of variability between studies. It is also important to note that some behavioural studies in this literature record participants "personal reactions" to the faces, not the ratings of the expressions themselves (Smith et al., 2013; Sutton et al., 2019). As we explained, our present interest is on the early neural processing of the facial expressions presented, not the participant's affective response to these faces, which occur at much later stages (Calvo & Nummenmaa, 2016; Hajcak et al., 2010 for reviews). Thus, the present study will focus on ratings of the expressions on the faces that are presented to participants.

Before we can rate a facial expression on arousal and valence, we need to visually decode the face (Calvo & Nummenmaa, 2016). The visual processing of these categorical expressions has been studied using scalp Event-Related Potentials (ERPs), enabling researchers to see these cognitive operations unfold at the millisecond level. The earliest ERP component of interest is the N170, a negative peak occurring 130-180ms after face onset. The N170 appears maximal on lateral posterior electrodes. The N170 historically indexes holistic face perception, or piecing together the features of a face into a whole percept (Itier & Taylor, 2004; Rossion, 2009; Rossion & Jacques, 2011). Whether categorical

expressions modulate the N170 is still unclear. Extraction of emotional content from a face is thought to occur only after structural encoding of the face (i.e., after the N170; Calvo & Nummenmaa, 2016). Yet, studies have shown reliable expression differences on this component, with a more negative N170 peak for threat-related (fear, anger) than other expressions (Hinojosa et al., 2015; Schindler & Bublatzky, 2020 but see Walentowska & Wronka, 2012; Wronka & Walentowska, 2011). Differences between neutral faces and other expressions (i.e., happiness) are less clear-cut, with only half of the literature showing such differences on the N170 (Schindler & Bublatzky, 2020). Further, very few studies have directly compared angry and fearful expressions directly. Those who did compare these expressions reported either more negative N170 amplitudes for fear than anger (Almeida et al., 2016; Batty & Taylor, 2003; Turano et al., 2017) or no difference between the two expressions (Calvo & Beltrán, 2013; Herbert et al., 2013; Smith et al., 2013).

N170 emotion effects may be related to differences in the physical structure of the facial expression (e.g., furrowed brow for anger and wide eyes for fear ;Bruce & Young, 1986; Han et al., 2021; but see Bruchmann et al., 2020, 2023) or the processing of emotional content occurring earlier than anticipated (Rellecke et al., 2013; Schacht & Sommer, 2009). If N170 emotion modulation is related to the emotional content of the face, one would assume that participants' perceived arousal and valence of an expression would also relate to these modulations. Many have speculated that the N170 is related to valence discrimination (Batty & Taylor, 2003; Calvo & Beltrán, 2013; Qiu et al., 2017) but it is only recently that studies have begun to empirically investigate this question. An experimental study (Almeida et al., 2016) and a computation-based study (Li et al., 2022) found that perceived face arousal modulated ERP waveforms during the N170, but not valence. It is noteworthy that these studies collected arousal and valence ratings in a separate study than their ERP participants, so these findings are not based on a direct brain-behaviour comparison. Although the literature is sparse and holds its limitations, the N170 may be sensitive to the perceived arousal and valence of a face, which would suggest that emotion-related processes are occurring during the N170 timing.

Following the N170 is the P2, a positive peak around 200ms after face onset, that occurs over posterior electrodes. Historically, this component has been ignored in emotion expression work, with only 18% of studies analyzing the P2 (Schindler & Bublatzky, 2020). Recent work has shown that the largest emotion differences occur between the N170 and P2 components, where fearful and angry faces elicit more negative amplitudes compared to happy and neutral faces (Durston & Itier, 2021; Han et al., 2021; Itier & Durston, 2023; Mueller et al., submitted; but see Hudson et al., 2021). This work has suggested that the P2 may represent the extraction of emotional content (e.g. arousal and valence) from the face (Durston & Itier, 2021; Han et al., 2021). However, with a limited number of studies looking at the

posterior P2, it is difficult to make claims on how categorical or continuous expressions modulate this component. If the P2 is involved in extracting the emotion from a stimulus as suggested by Han et al. (2021), then its amplitude should relate to the arousal and valence ratings of expressions. Only one study has explicitly investigated this. Li et al. (2022) found that arousal related to amplitudes during the N170-P2 waveform (150-200ms), and both arousal and valence were related to later components after 230ms. Yet, they found no emotional information related to P2 peak amplitudes. As this unique study is based on between-subjects' brain-behaviour comparisons, more experimental work is needed to replicate these effects.

Lastly, the early posterior negativity (EPN) is a negative slow-wave component following the P2, traditionally analyzed from 200-350ms. Previous work has suggested that the EPN indexes the allocation of attentional resources toward emotional and threatening stimuli in our environment (Ohman, 2009; Schupp, Junghöfer, et al., 2004). In classic analyses where the EPN is measured as a mean amplitude across a predefined time window, the EPN amplitude is more negative for fearful and angry expressions than other expressions (Schindler & Bublatzky, 2020). Recent mass univariate (MU) analyses which analyze all time points and all electrodes, only partially support this interpretation, finding fearful and happy faces differing from neutral expressions on this component (Itier & Durston, 2023), but reporting no difference between threat-related (fearful) and happy expressions (Durston & Itier, 2021; Hudson et al., 2021; Itier & Durston, 2023). Further, only a handful of studies have compared fearful and angry expressions on the EPN, with most finding no difference between them (Herbert et al., 2013; Smith et al., 2013). These previous studies suggest that arousal is more likely to relate to EPN amplitudes than valence. Support for this contention comes from reports of similar arousal ratings of happy, angry, and fearful expressions (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Herbert et al., 2013; Smith et al., 2013; Sutton et al., 2019), and similar EPN magnitudes for these same emotions (Durston & Itier, 2021; Herbert et al., 2013; Hudson et al., 2021; Itier & Durston, 2023; Smith et al., 2013). While this proposition suggests that EPN effects are related to arousal (Calvo & Beltrán, 2013; Langeslag & van Strien, 2018), when considering participants expression ratings, Li et al. (2022) found that both perceived arousal *and* valence were extracted from facial expressions during the EPN time window. However, no other study has attempted to study how the EPN is related to emotional information on a stimulus or participant level, and more work is needed.

Overall, no study has directly compared arousal or valence ratings of facial expressions to ERP amplitudes within-subjects. Therefore, the direct link between perceived arousal and valence in face expressions and ERP responses to these facial expressions still awaits empirical demonstration, which the present study aims to provide. This study is a critical step for understanding the neural processing of

facial expressions and validating theories used in the field. Further, many inconsistencies remain across the emotion processing field, possibly due to multiple factors. First, most ERP studies on the topic are underpowered, with low numbers of trials (less than 50 trials per condition after artifact rejection) and low participant sample sizes (typically less than 30). Second, some suggest that these studies use error-prone statistics (Luck & Gaspelin, 2017), limiting the reliability of the findings. Third, most experiments do not control gaze location, despite studies showing that fixation location alters the neural processing of faces and facial expressions (Itier & Durston, 2023; Nemrodov et al., 2014; Siklos-Whillans & Itier, 2024). This is particularly important for threat-related expressions, as we instinctively saccade to the eye (fear) or brow (anger) region when they are presented (Atkinson & Smithson, 2020; Scheller et al., 2012).

To address these gaps in the literature, the present study used a within-subjects design to directly compare the neural processing of angry, fearful, happy, and neutral faces using ERPs. We gathered arousal and valence ratings of the expressions of the presented faces, with faces drawn from multiple face databases. We controlled gaze location and used robust timepoint-by-timepoint Mass Univariate (MU) statistics. We conducted three separate ANOVA models, one only considering the categorical emotions to compare to recent studies using MU analyses, one considering category by arousal interactions and another considering category by valence interactions. We hoped that these analyses would allow us to determine which emotion category differences are related to valence and/or arousal differences, and to clarify inconsistencies in results and theories in the field.

Our predictions were as follows. For the mean arousal ratings, we anticipated that happy, angry, and fearful expressions would not differ but would be rated as more aroused than neutral faces (Herbert et al., 2013; Smith et al., 2013; Sutton et al., 2019). For valence ratings, we anticipated happy faces would be the most positive, followed by neutral, then fearful and angry faces, which would not differ (Herbert et al., 2013; Smith et al., 2013; Sutton et al., 2019). Generally speaking, we expected that the facial expression ratings would follow the circumplex model (Carroll & Russell, 1996). For ERP data, we predicted replicating more negative N170, P2, and EPN amplitudes for fearful and angry expressions compared to happy and neutral faces, maximally between 180-200ms, replicating recent MU analyses studies (Durston & Itier, 2021; Itier & Durston, 2023; Mueller et al., submitted). We further predicted that these early effects (N170-P2) would be related to arousal differences between the faces, whereas later effects (EPN) would be linked to both arousal and valence (Li et al., 2022).

Chapter 2
Methods

The study was preregistered on OSF.

2.1 Participants

Through the University of Waterloo, 101 young adult participants registered for the study. Twenty-two participants signed up for pay (up to $36) through poster recruitment, and 79 signed up for course credit and a small cash payment (up to $12) through the UW SONA system. All participants reported no history of psychiatric or neurological disorders, brain injury or lesions. Everyone had normal or corrected-to-normal vision and had been in North America for more than ten years. Six individuals were not able to participate due to eye tracking and EEG recording difficulties, leaving 95 participants who engaged in the experiment. Two were rejected for falling asleep during the experiment, eleven were rejected due to corrupted eye-tracking data, and two were rejected due to quitting following the first task (see procedures). This left a total of 80 participants in the present analysis (40 females; 70 right-handed; M_{age} (SD) = 21 yrs (2.97)).

2.2 Stimuli

A total of 40 identities were used as face stimuli. Ten identities (five female) were each selected from four different databases: NIMSTIM (Tottenham et al., 2009), Chicago Face Database (Ma et al., 2015), Radboud Face Database (Langner et al., 2010), and FACES Database (Ebner et al., 2010). Only Caucasian individuals with little to no makeup or facial hair were used. Fearful, happy, angry, and neutral expressions were used from each of the chosen identities, for a total of 160 (40 x 4 expressions) unique stimuli. Identities were selected based on high emotion recognition accuracy from the norming studies. Fearful and happy expressions used open mouth, and angry and neutral faces used closed mouth. This was to ensure consistency across databases, as not all databases offer both open and closed-mouth options.

Faces were edited with GIMP (GNU Image Manipulation Program; v2.10.32). Coloured stimuli were cropped into an ellipse with the center sitting just above the tip of the nose. Any potentially distracting or attention-grabbing features on the faces (acne, scars, unibrows, etc.) were edited out. Faces were centered on a white background. The SHINE toolbox was used to equate the images for contrast and pixel intensity (Willenbockel et al., 2010). Images that were overly distorted after SHINE editing were airbrushed to create an even skin tone, and then the face set was SHINED again. At the end of editing, photos were highly similar, with an average luminance of 238.86 (SD = 0.139), pixel intensity of 0.933 (SD = 0.138) with a structural similarity index measure (SSIM) of 0.997, where a value of one would indicate the

images are identical on contrast and pixel intensity. Once added into the experiment, photos were re-sized so the faces would comprise a visual angle of 5.39° width x 7.71° height when sitting 70cm from the screen.

2.3 Procedure

Participants came into the lab and reviewed and signed an informed consent letter. After participants consented to participate, and answered additional questions, they were fitted with an EEG cap, ensuring proper fit with the 10/20 international system. Following cap fitting, participants were led into a separate room where they completed demographics and additional questionnaires[1]. Once the questionnaires were completed, the researchers returned to the testing room and began prepping the EEG cap with saline gel and setting up the eye tracking (see data acquisition section). During the experiment, participants sat 70 cm from the computer screen, stabilizing their head on a chin rest. First, an eight-minute baseline recording occurred, including four sessions of one minute with participant's eyes open looking at a fixation cross, and one minute of eyes closed. The baseline EEG and self-report measures are not included in this report.

Participants completed a total of four tasks, before which instructions were delivered verbally by the researcher and also read by the participant. Only the first two tasks are relevant to the present report, and thus the second two tasks will not be discussed. The first task was a gender discrimination task. Participants fixated on a cross in the middle of the screen for 200ms before a face was presented for 250ms, and then had 2000ms to respond. Trials where participants took over 10 seconds to fixate on the cross at the beginning of the trial prompted a drift correction. Responses were given using the left and right arrow keys, which was counterbalanced across participants. Participants were given 8 practice trials before commencing the experimental trials. The experiment consisted of 12 blocks of 40 faces, for a total of 480 trials (120/condition). Faces from each database were separated by block, to prevent startle effects due to photograph graphical differences (quality, colour saturation, etc.). Blocks were presented in a randomized order. Eye tracking was re-calibrated after 6 blocks, or after any block with more than one drift correction.

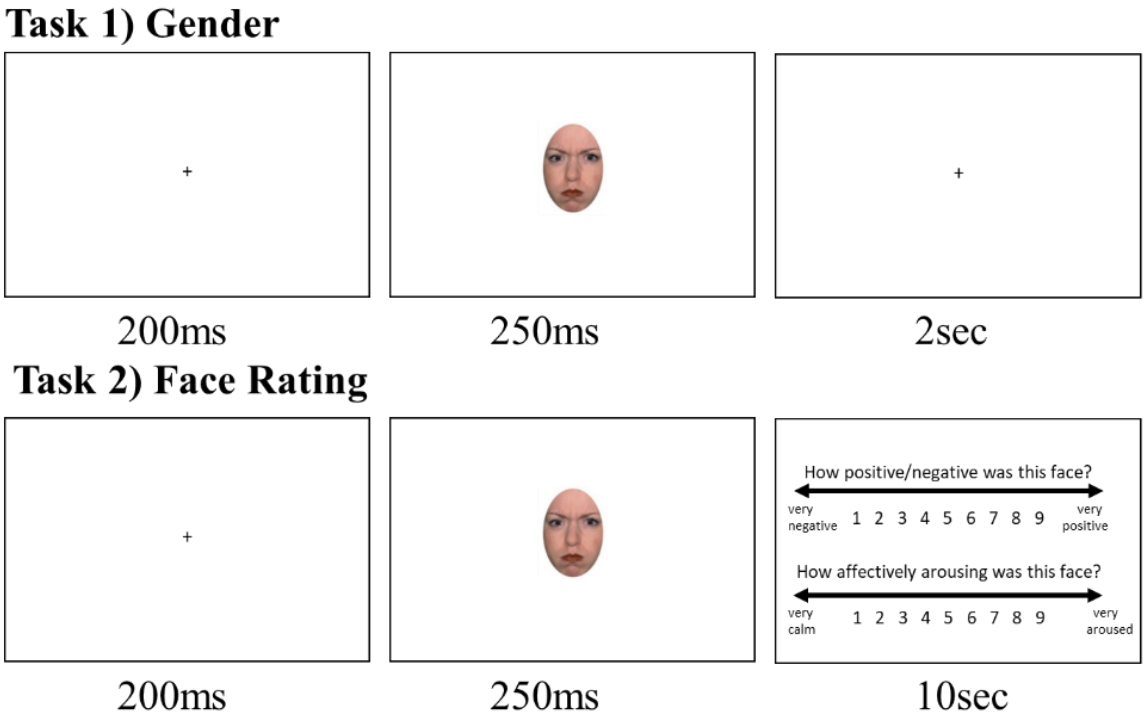
Following the gender discrimination task, participants completed a face rating task, in which no EEG data was recorded. Participants viewed the 160 unique faces again, using the same timing and trial progression as the gender task. However, instead of having 2000ms to complete a gender discrimination

[1] Demographics included age, biological sex, race, years of education, handedness, vision. Additional questionnaires included STICSA (Ree et al., 2008); STAI (Spielberger, 1983); SPIN (Connor et al., 2000); TRIPM (Patrick, 2010; Patrick et al., 2009); LSRP (Levenson et al., 1995).

task, they had 10,000ms to rate the face on how positive/negative it was, and how affectively arousing the face was on scales from 1-9 (Figure 1). The wording of these questions was chosen based on previous studies targeting the emotional properties of the expression (Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Eisenbarth & Alpers, 2011). Prior to the rating task, participants were given verbal and written instructions to ensure they were rating the perceptual properties of the face, as opposed to how the face made them feel. Researchers ensured they understood the focus of the rating before beginning the task. Participants completed 4 blocks of 40 faces, for a total of 160 trials. The order of presentation (valence or arousal question presented on the top of the screen) was counterbalanced across participants (but was the same from trial to trial for a given participant). Eye tracking was re-calibrated between each task, or after any block that contained more than one drift correction.

Figure 1

Visual depiction of the task and trial progression in the study.



2.4 Eye Tracking and EEG Acquisition

EEG was continuously recorded during the endorsement task at 500 Hz by an Acti64Champ (Brain Vision Solutions Inc.) with electrode impedances kept below 50 kOhms. Custom caps under the 10-20 system extended included 64 recording electrodes including PO9/PO10 and TP9/TP10 for additional

coverage. Electrode sites F1, F2, AF3, and AF4 were excluded from the recording montage. Electrode Cz was used as the online reference, but data was re-referenced offline to the average reference.

2.5 Data Processing

EEG trials were rejected 1) if a saccade exceeding the 1.4° region of interest surrounding the fixation cross center was recorded and 2) if participants did not complete both tasks (gender and rating) for the corresponding face within the allotted time (2 and 10 seconds respectively). Overall, this led us to reject 22.28 (SD = 17.96) trials per condition on average[2].

Remaining trials were then processed using the EEGLab (Delorme & Makeig, 2004) and ERPLab (http://erpinfor.org/erplab) MATLAB toolboxes, and the signal was segmented from -100ms before the face onset to 350ms after the face onset. Data were filtered with a 0.01–30 Hz bandpass filter. Trials containing artifacts exceeding ± 70μV on any electrodes were rejected automatically and the remaining trials were visually inspected and further rejected when remaining artifacts were visible. Participants who had a high number of trials automatically rejected were inspected for noisy channels, which were then interpolated as needed. These cleaning steps resulted in rejecting an additional 8.64 (SD = 12.35) trials per condition on average. The final cleaned datasets for the 80 participants had an average of 86.30 (SD = 20.68) trials per condition[3].

2.6 Data Analysis

Behavioural data analyses were conducted in JASP (version 0.17.2.1). Average ratings for each emotion were computed for each participant. This left us with eight rating values per participant, one of valence and one of arousal for each of the four expressions. Arousal and valence ratings were entered separately into repeated measures ANOVAs, using both traditional and Bayesian models. This allowed us to determine if the expressions were rated differently (as expected) on arousal and valence, and if this held up to Bayesian inference. We set up the Bayesian model with the default expected priors favoring the alternative hypothesis (i.e., BF_{10}) as we expected the expressions to be rated differently from each other. All other details were left to JASP's default. BF_{10} values were interpreted in accordance with current standards (Lee & Wagenmakers, 2014; Stefan et al., 2019), where BF_{10} values above 1 provide evidence for the alternative hypothesis, with values above 100 providing extreme evidence (see Stefan et al., 2019, table 1 for a details). Effect sizes and 95% confidence intervals were computed, where Bayesian main

[2] Number of trials rejected per expression condition, on average (with standard deviation): Neutral = 21.91(17.92), Happy = 19.48(16.42), Angry = 22.98(19.87), Fearful = 24.76(21.60)
[3] Neutral = 86.18(20.09), Happy = 89.15(19.76), Angry = 86.00(22.30), Fearful = 84.00(24.00)

effects used the coefficient of determination (R^2), traditional ANOVA main effects used eta squared (η^2), and paired comparisons used Cohen's d (*d*).

ERP data analyses were conducted in LIMO EEG (EEG-Master version; https://github.com/LIMO-EEG-Toolbox/limo_tools; Pernet et al., 2011). This toolbox takes a hierarchical approach. At the first level, LIMO computed a regression model on each participant's trial-level data. LIMO EEG uses a hierarchical General Linear Model (GLM) where a regression-based analysis is first computed, at each time point and electrode, on the variance between trials of each condition within each participant. This first level analysis ensures individual variance is being accounted for and outputs regression coefficients, which are then used in the group statistical analysis. The outputs from this first level (i.e., estimate regression [beta] parameters) are then entered into the group level model specified by the researcher. At both levels, LIMO creates the models for each electrode and each time point. In this study, this meant tests were ran from -100 to 350ms (255 data points) at 64 electrodes, for a total of 14400 tests for each participant in the first level, and in total for the second level. For more details on the fundamentals behind this tool box, see Pernet et al. (2011).

At the second level, LIMO requires electrode locations to be defined using a neighbourhood matrix, specifying which electrodes correlate with each other, and how far apart they are in space. For our custom electrode cap we created a cap-specific neighbouring matrix to ensure all electrodes which should be clustered together were being correlated, and set the distance of electrodes to be 0.4799 (used previously with this montage; Hudson, 2022). Then, all three models were entered into a one-way ANOVA (1x4 emotions) comparing the ERP amplitudes in response to each emotion category with alpha levels set to 0.05, 1000 bootstraps, and a cluster mass correction where the 1-α range of data clusters in the distribution survives the correction (Pernet et al., 2015). Note that Hotelling T-tests are used in these models to account for the covariance between measures; thus, there is no need to adjust for sphericity in the ERP data.

In the present analyses, three different regression models were computed at the first level using weighted least squares. The first model simply included the categorical information (i.e., the emotion categories), and the subsequent second-level ANOVA revealed electrodes and time-points when the expressions significantly differed from each other. The second model included the emotion categories as a categorical condition, and arousal ratings as a regressor. Thus, the output from the first level "arousal" model gives us regression parameters associated with the relationship between EEG activity and arousal ratings. A subsequent ANOVA revealed whether the relationship between arousal and EEG data differed between emotions. Conceptually, although not mathematically, this represents an interaction between emotion category and arousal rating, allowing us to infer which emotion effects are related to perceived

arousal as measured by participants' arousal rating for each face (see Pernet et al., 2021 for a similar analysis). The third, and final model, operated the same as the second, however this time valence ratings were entered at the first level instead of arousal ratings[4], allowing us to assess which emotion effects are related to perceived valence as measured by participants' valence rating for each face. These ANOVAs were run at every time point and electrode using 1000 bootstraps and $p < 0.05$. For each model, follow-up *F*-contrasts were run on the whole epoch, using stringent Bonferroni corrected *p*-values of 0.008 to account for the number of comparisons conducted.

Lastly, all ERPs and difference waves were created using the difference wave and central tendency function in LIMO EEG. Chosen measures of central tendency were standard means within-subjects, and 20% trimmed means across subjects. Confidence intervals were computed with an alpha corresponding with the follow-up tests (α=.008). Further, LIMO EEG uses Bayesian Highest Density Interval (HDI) as a confidence interval around the difference wave, which allows us to be confident in the null when plotting the results, if the difference wave and its confidence interval include zero.

[4] No model including both arousal and valence was used, as all that was highlighted was where the two models shared significant data points.

Chapter 3
Results

3.1 Arousal and Valence Ratings

Average arousal ratings were normally distributed in terms of skew and kurtosis. Average valence ratings were normally distributed, except for neutral expressions. Neutral faces had a kurtosis of 11, just outside of the normal kurtosis range (-10 to 10), indicating a slightly abnormal concentration of scores throughout the distribution (Kline, 1998). However, this was not concerning. Values were over concentrated at the midline of the scale, showing the faces were perceived as a true neutral. Further, due to the trial-by-trial nature of the ERP analyses, and the small deviation from the recommended guidelines, no transformations were conducted to normalize the data prior to analyses. To visualize the distributions, please see Figure 2 and Table 1.

There was a main effect of emotion category on mean arousal ratings, with a large effect size, even when corrected for sphericity using Greenhouse-Geisser correction ($F(2.158, 170.451) = 198.498$, $p < .001$, $MSE = 1.635$, $\eta^2 = 0.715$, $BF_{10} = 2.512x10^{66}$, R^2 [95% CI] = 0.683 [0.647 0.713]). Post-hoc tests showed that fear was rated highest in arousal (Table 1; Figure 2a), with extremely strong evidence for fear being more aroused than neutral ($t = -22.961$, d [95% CI] = -3.197 [-3.968 -2.426], $p < .001$, $BF_{10} = 2.832\times10^{+33}$), happy ($t = -6.583$, $d = -0.917$ [-1.334 -0.499], $p < .001$, $BF_{10} = 323436.471$), and angry ($t = -4.929$, $d = -0.686$ [-1.084 -0.289], $p < .001$, $BF_{10} = 4.718\times10^{+13}$) faces. Angry expressions were rated the second highest on arousal, and extremely strong evidence suggested it was rated significantly higher than neutral ($t = -18.032$, $d = -2.511$ [-3.158 -1.864], $p < .001$, $BF_{10} = 1.471\times10^{+30}$). However, angry and happy expressions did not differ on arousal ratings, with no Bayesian evidence for the alternative hypothesis ($t = 1.654$, $d = -0.230$ [-0.603 -0.143], $p = .597$, $BF_{10} = 0.318$). Lastly, there is extremely strong evidence for happy expressions being rated higher on arousal than neutral ($t = -16.378$, $d = -2.280$ [-2.888 -1.673], $p < .001$, $BF_{10} = 1.408\times10^{+19}$).

There was also a main effect of emotion category on valence ratings, again with large effect sizes even when corrected for sphericity ($F(1.774, 140.179) = 939.104$, $p < .001$, $MSE = 0.552$, $\eta^2 = 0.922$, $BF_{10} = 9.221x10^{154}$, R^2 [95% CI] = 0.902[0.894 0.910]; Figure 2b). Every expression differed significantly from each other, with extremely strong Bayesian evidence. Happy faces were rated significantly more positive than neutral ($t = -29.162$, d [95% CI] = -4.453 [-5.478 -3.429], $p < .001$, $BF_{10} = 1.747x10^{40}$; Table 1), angry ($t = 47.893$, $d = 7.314$ [5.717 8.911], $p < .001$, $BF_{10} = 7.374x10^{46}$), and fearful ($t = 43.709$, $d = 6.675$ [5.208 8.142], $p < .001$, $BF_{10} = 4.240x10^{45}$) faces. Neutral faces were also positive than angry ($t = 18.731$, $d = 2.861$ [2.133 3.588], $p < .001$, $BF_{10} = 1.716x10^{37}$) and fearful ($t = 14.546$, $d =$

2.221 [1.601 2.842], $p < .001$, $BF_{10} = 15.936x10^{26}$) faces. Lastly, fearful faces were less negative than angry (*t = -4.185*, *d* = -0.639 [-1.066 -0.212], $p < .001$, $BF_{10} = 4.030x10^{6}$).

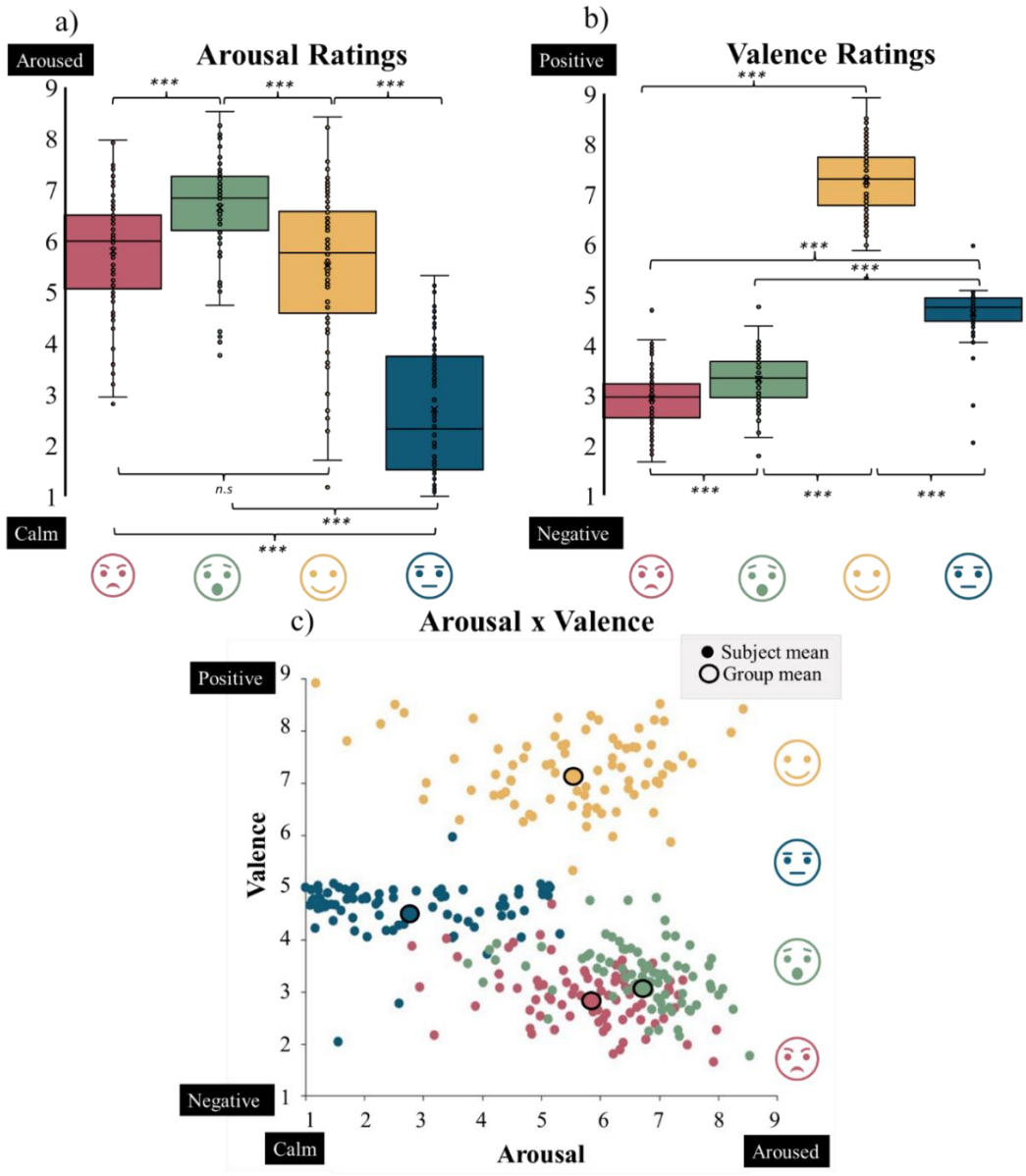
Table 1

Means and standard deviations for arousal and valence ratings of each expression.

	Arousal		Valence	
	Mean	Std. Deviation	Mean	SD
Angry	5.79	1.11	2.9	0.56
Fear	6.63	0.99	3.31	0.58
Happy	5.51	1.45	7.26	0.71
Neutral	2.70	1.32	4.62	0.49

Figure 2

Visual displays of mean arousal and valence ratings, for each participant, for each emotion.



Note. Blue is neutral, yellow is happiness, green is fear, and pink is anger. Box plots show the distribution of arousal (a) and valence (b) scores for each emotion and their comparisons (p<.001***; not significant $^{n.s.}$). We also present a scatter plot (c), with arousal ratings on the x-axis and valence ratings on the y-axis. Each dot on this scatter represents an individual participant's average arousal and valence rating for the corresponding emotion. Circles with black boarders indicate the group mean ratings for each expression. See Appendix A Figure 1 for the scatter plot compared with the circumplex model.

When viewing the circumplex scatter plot (Figure 2c), it does appear that participants consistently rate these facial expression categories in accordance with the circumplex model, although no statistical analyses were computed (Gerber et al., 2008; Russell, 2003; Russell & Bullock, 1985; Appendix A Figure 1). Our results revealed visually lower arousal ratings than expected, but similar valence ratings (Gerber et al., 2008; Russell & Bullock, 1985). Further, we report a large amount of within-cell variance in arousal ratings. Happy expressions span from low to high arousal (min = 1.173, max = 8.516), neutral expressions were rated as low to medium arousal (min = 1.00, max = 5.310), and fearful and angry expressions were rated as medium to high arousal (min_{Fear} = 3.750, max_{Fear} = 8.524; min_{Anger} = 2.805, max_{Anger} = 7.964), with a few participants rating these faces as low arousal.

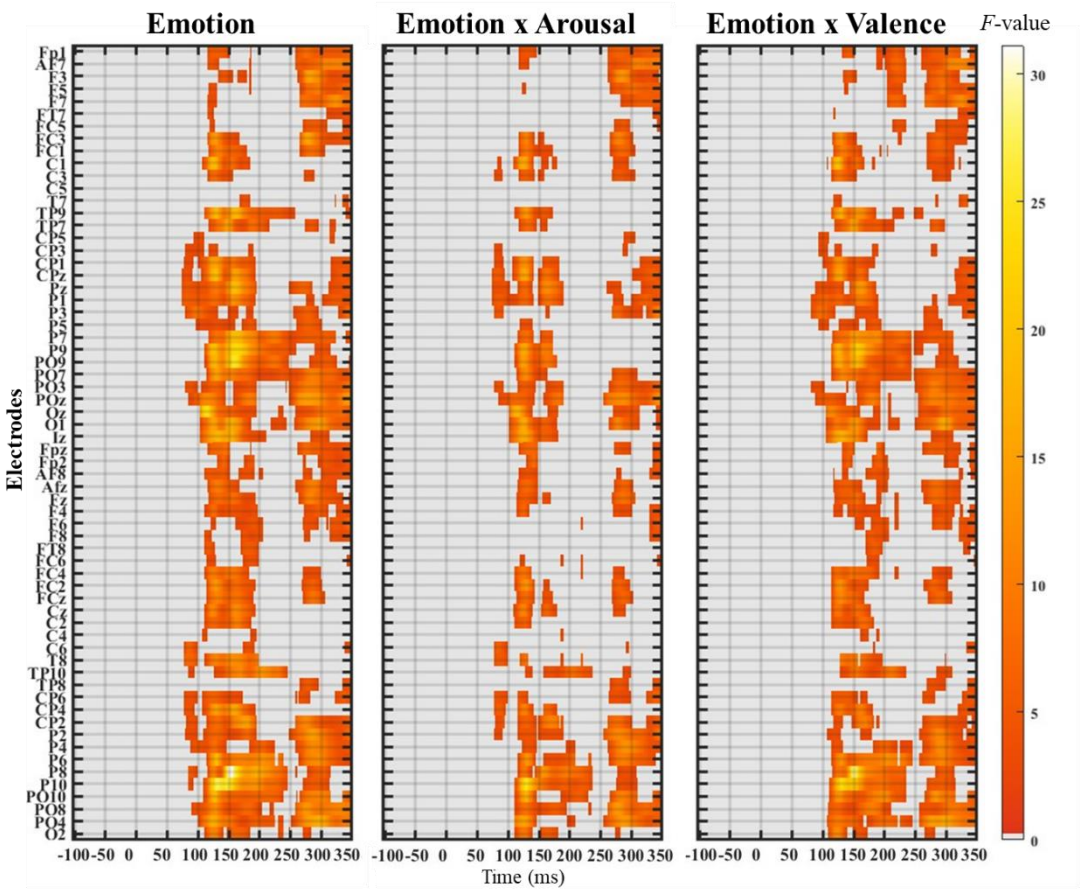
3.2 ERP analyses

3.2.1 Main Effects

All three models revealed a significant effect of emotion and had a large amount of spatial and temporal overlap (Figure 3). The original analysis (i.e., main effect of emotion) was significant from 74-348ms on most electrodes across the scalp (max at 152ms on P8 [N170 peak]; $F(3, 79) = 31.13$, $p = 0.001$). The arousal analysis (equivalent to an arousal by emotion interaction) spanned the entire scalp from 74ms-236ms (encompassing P1, N170, P2, EPN; max at 130ms on P10 ($F(3, 79) = 25.20$, $p = 0.001$ i.e., during the P1-N170 interval) and 254-348ms (EPN; max at 286ms on PO4 ($F(3, 79) = 13.79$, $p = 0.001$). The valence analysis (equivalent to a valence x emotion interaction) was significant across the entire scalp, and temporally from 82ms-244ms (encompassing P1, N170, P2, EPN; max at 152ms on P8 [N170 peak]; $F(3, 79) = 28.62$, $p = 0.001$) and 248-348ms (EPN; max at 296ms on O1; $F(3, 79) = 16.11$, $p = 0.001$).

Figure 3

Main effects of emotion as revealed by original (emotion), arousal, and valence analyses (p<.05).



Note. Plots were created in the LIMO toolbox. Time in milliseconds is along the X axis of each plot, and electrodes are along the Y axis. The colour bar represents the *F*-Values of significant datapoints.

3.2.2 Neutral-happy expression contrasts

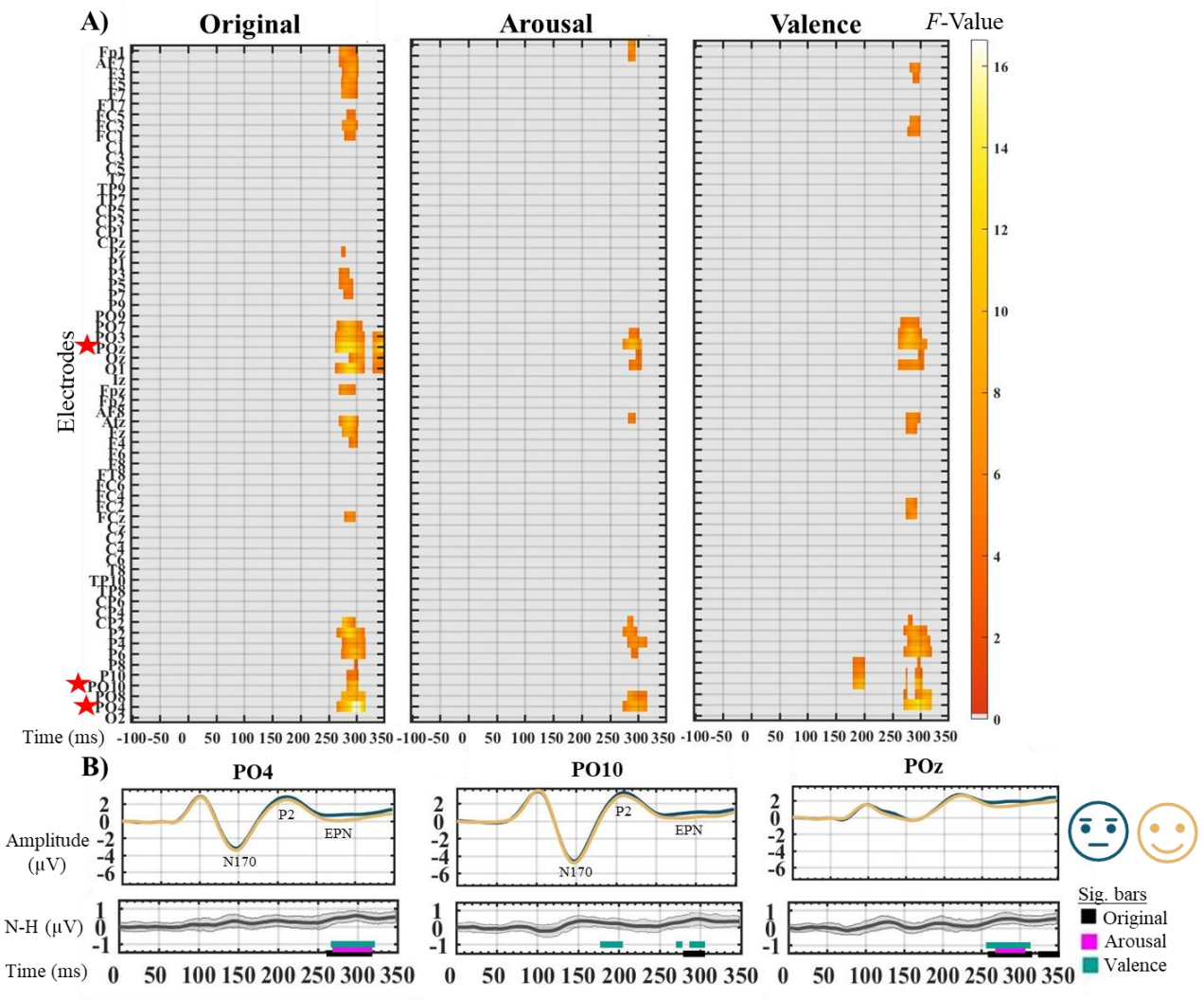
When we compared neutral and happy expressions in the original model (i.e., without ratings) the analysis was significant mainly on the late EPN. From 262-314ms the analysis was significant on parietal, occipital, and parietal-occipital electrodes (Figure 4; Appendix B Table 1; max at 298ms on PO4; $F(1, 79) = 16.65$, $p = .001$, [N-H] $\Delta\mu V = 0.62$), and at frontal and fronto-central electrodes (max at 286ms on AFz; $F(1, 79) = 10.50$, $p = .001$, [N-H] $\Delta\mu V = -0.66$). The last significant data points were later, from 328-348ms on left parietal-occipital sites (max at 348ms on POz; $F(1, 79) = 12.29$, $p = .001$, [N-H] $\Delta\mu V = 0.53$). The arousal analysis was significant in a similar manner, spanning from 272-314ms. These results were significant on parietal and parietal-occipital sites (max at 290ms on POz*;* $F(1, 79) = 9.87$, $p = .001$, [N-H] $\Delta\mu V = 0.53$), as well as a few left frontal sites (max at 284ms on Fp1; $F(1, 79) = 6.42$, $p = .002$, [N-H] $\Delta\mu V = -0.44$). The valence analysis began earlier than the original and arousal analyses. These

early significant data points were from 180-200ms (N170-P2 interval) on right parietal-occipital electrodes (max on PO10 at 198ms*; F*(1, 79) = 9.50, *p* = .001, [N-H] ΔμV = 0.24). The rest of the results overlapped with the other analyses: 260ms-318ms on posterior sites, (max at 296ms at PO4, *F*(1, 79) = 13.23, *p* = .001, [N-H] ΔμV = 0.61) and frontal electrodes (288ms on FCz, *F*(1, 79) = 7.18, *p* = .001, [N-H] ΔμV = -0.40).

In summary, happy expressions elicited more negative amplitudes than neutral expressions on the EPN, which was related to both arousal and valence ratings. Further, there was a unique valence effect between the N170 and P2 components.

Figure 4

Results from the neutral and happy expression contrasts (p<.008).



Note. A) Plots representing the *neutral and happy expression contrasts* for the original (emotion), arousal, and valence analyses (p<.008). Time in milliseconds is along the X axis of each plot, and electrodes are along the Y axis. Red stars beside electrode names indicate electrodes plotted in section B. The colour bar represents the F-Values of significant datapoints, where grey indicates insignificant datapoints. F-values are corrected using cluster mass correction for multiple comparisons. B) ERPs (top) and difference wave (bottom; neutral-happy) on key electrodes. ERP waveforms elicited by neutral faces are presented in blue and happy faces in yellow. On the difference wave plots, black significance bars indicate when electrodes were significant in the original analysis, pink bars indicate when the arousal analysis was significant, and blue bars indicate when the valence analysis was significant. Confidence intervals on the difference wave plots were computed with 20% trimmed means and Bayesian bootstrapping at α = .008.

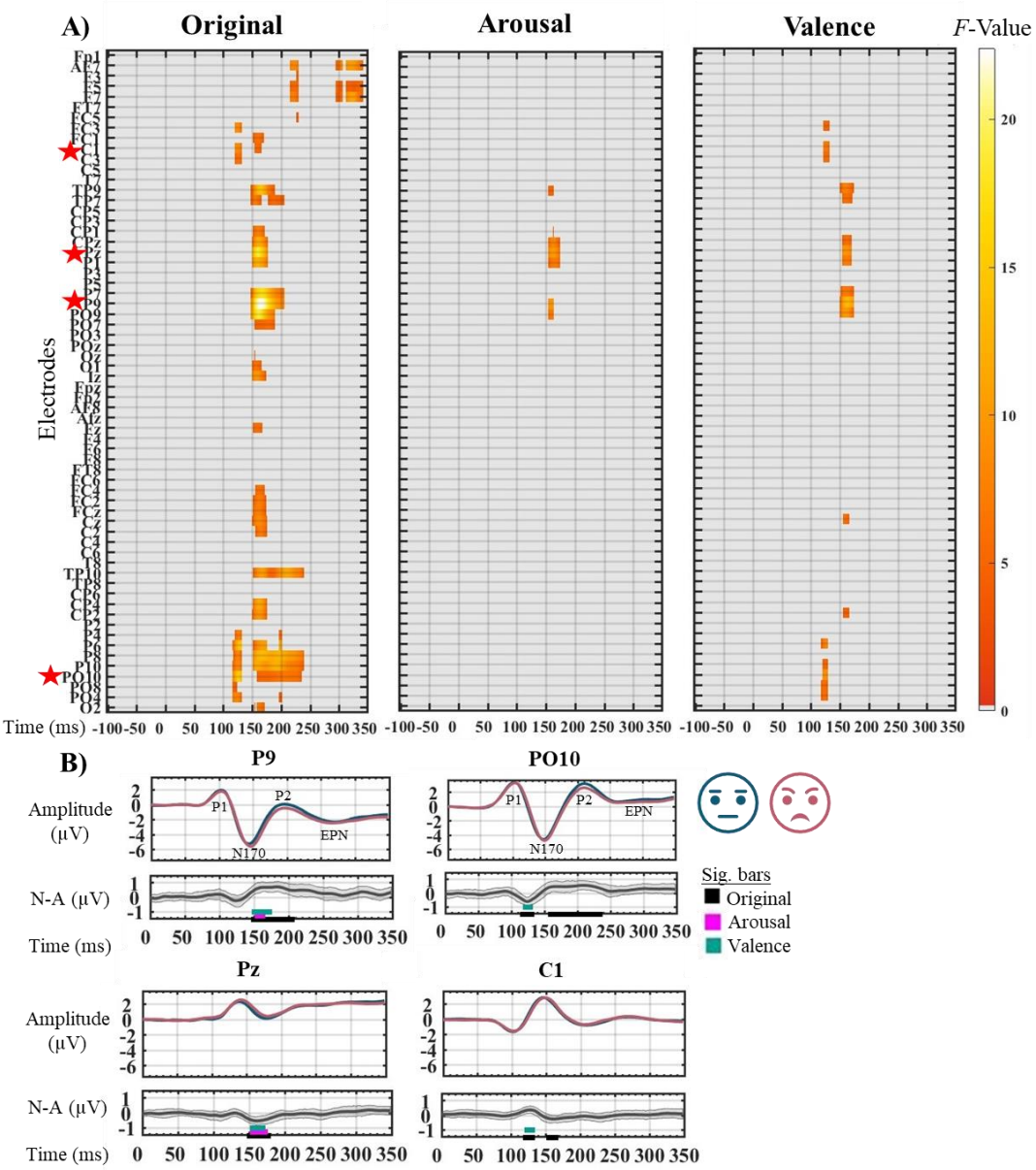
3.2.3 Neutral-angry expression contrasts

In the original model, neutral and angry expressions differed initially during the P1-N170 interval, from 116ms-130ms on right parietal electrodes (Figure 5; Appendix B Table 2; max at 126ms on PO10, F(1, 79) = 15.88, p = .001, [N-A] ΔμV = -0.60) and left central electrodes (max at 124ms on FC3, F(1, 79) = 9.08 p = .005, [N-A] ΔμV = 0.30). Neutral and angry faces also differed on the N170-P2 interval, including N170 and P2 components, from 148ms-238ms on central, temporal, and parietal-occipital sites (max on P9 at 164ms; F(1, 79) = 22.41, p = .001, [N-A] ΔμV = 0.69) and on left frontal electrodes (max at 222ms on AF7; F(1, 79) = 8.84, p = .003, [N-A] ΔμV = -0.48). The arousal analysis was significant around the N170, from 154ms-172ms on left temporal, parietal, and occipital electrodes sites (max on P9 at 160ms; F(1, 79) = 9.69, p = .004, [N-A] ΔμV = 0.67) and left and central parietal electrodes (max on Pz at 162ms; F(1, 79) = 10.23, p = .001, [N-A] ΔμV = -0.53). The valence model aligned more with the original model than the arousal model did. It was significant before the N170, from 118ms-130ms on right parietal-occipital electrodes (max at PO10 at 124ms, F(1, 79) = 9.33, p = .001, ΔμV = -0.60) and left central electrodes (max at 124ms on C1, F(1, 79) = 7.15, p = .003, ΔμV = 0.36). The difference between these emotions also related to valence around the N170, significant from 150-172ms on central-parietal electrodes (max on Pz at 160ms; F(1, 79) = 9.55 p = .001, ΔμV = -0.53) and left temporal and parietal electrodes (max at 162ms on P9; F(1, 79) = 13.45, p = .001, ΔμV = 0.68).

Overall, neutral expressions elicited more negative amplitudes than angry expressions during the P1-N170 interval but more positive amplitudes than angry expressions on the N170-P2 interval, including the P2 components. Differences between neutral and angry faces before and during the N170 were related to valence ratings, while arousal was only related to this contrast briefly in the left hemisphere just after the N170.

Figure 5

Results from the neutral and angry expression contrasts (p<.008).



Note. A) Plots representing the *neutral and angry expression contrasts* for the original (emotion), arousal, and valence analyses (*p*<.008). Time in milliseconds is along the X axis of each plot, and electrodes are along the Y axis. Red stars beside electrode names indicate electrodes plotted in section B. The colour bar represents the F-Values of significant datapoints, where grey indicates insignificant datapoints. F-values are corrected using cluster mass correction for multiple comparisons. B) ERPs (top) and difference wave (bottom; neutral-angry) on key electrodes. ERP waveforms elicited by neutral faces are presented in blue and angry in pink. On the difference wave plots, black significance bars indicate when electrodes were

significant in the original analysis, bright pink bars indicate when the arousal analysis was significant, and blue bars indicate when the valence analysis was significant. Confidence intervals on the difference wave plots were computed with 20% trimmed means and Bayesian bootstrapping at $\alpha = .008$.

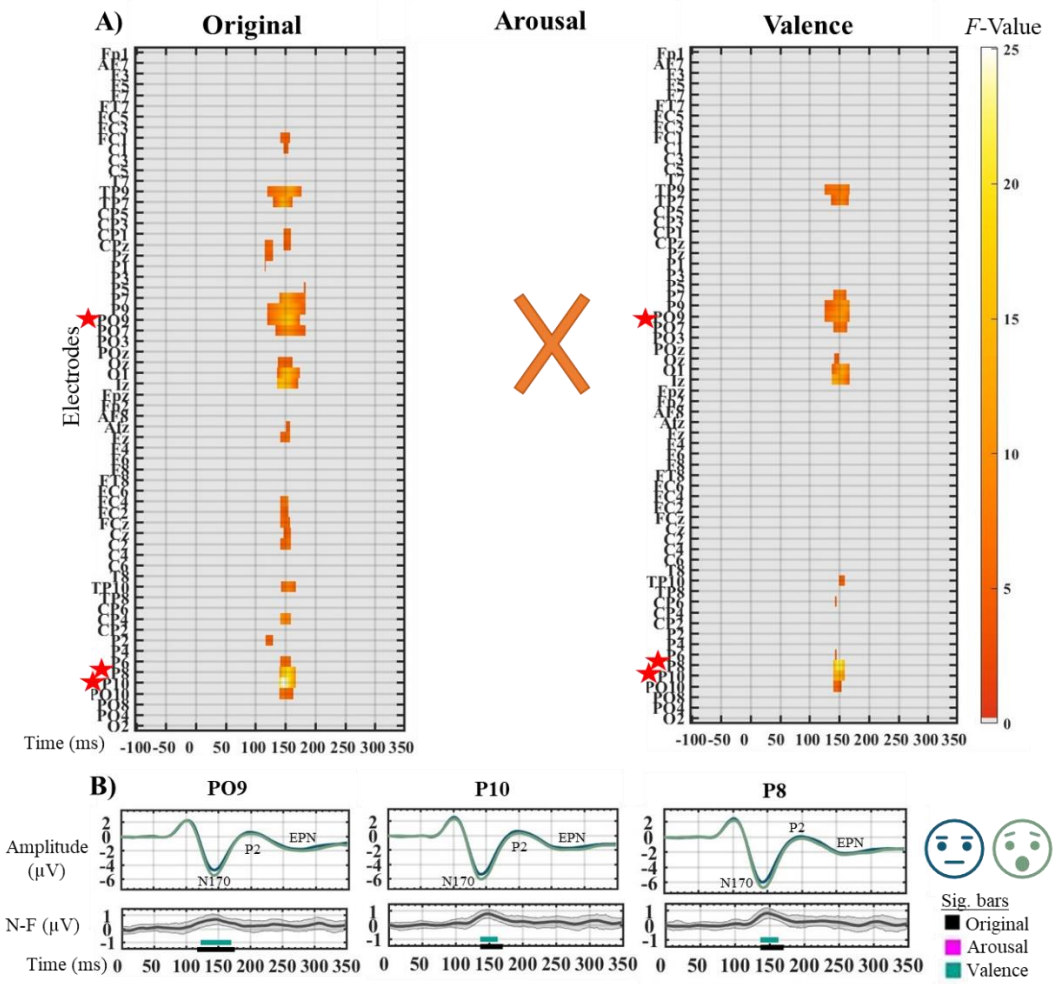
3.2.4 Neutral-fearful expression contrasts

In the original model, neutral and fearful faces differed on the N170 peak and slightly after, towards the P2, at parietal-occipital sites (Figure 6; Appendix B Table 3; 120 -182ms; max at 148ms on P10; $F(1, 79) = 25.08$, $p = .001$, [N-F] $\Delta\mu V = 0.79$). The arousal model was not statistically significant when applying the correction for multiple comparisons. The valence model was significant around the N170, from 126-166ms on temporal, parietal, and occipital electrodes (max on P8 at 150ms; $F(1, 79) = 21.89$, $p = .001$, [N-F] $\Delta\mu V = 0.82$).

Overall, fearful expressions elicited more negative N170 amplitudes than neutral expressions, and this was related to perceived valence, not arousal.

Figure 6

Results from the neutral and fearful expression contrasts (p<.008).



Note. A) Plots representing the *neutral and fearful expression contrasts* for the original (emotion), arousal, and valence analyses (p<.008). Time in milliseconds is along the X axis of each plot, and electrodes are along the Y axis. Red stars beside electrode names indicate electrodes plotted in section B. The colour bar represents the F-Values of significant datapoints, where grey indicates insignificant datapoints. F-values are corrected using cluster mass correction for multiple comparisons. B) ERPs (top) and difference wave (bottom; neutral-fear) on key electrodes. ERP waveforms elicited by neutral faces are presented in blue and fear in green. On the difference wave plots, black significance bars indicate when electrodes were significant in the original analysis, bright pink bars indicate when the arousal analysis was significant, and blue bars indicate when the valence analysis was significant. Note the lack of pink bars due to lack of significance for the arousal model. Confidence intervals on the difference wave plots were computed with 20% trimmed means and Bayesian bootstrapping at $\alpha = .008$.

3.2.5 Happy-angry expression contrasts

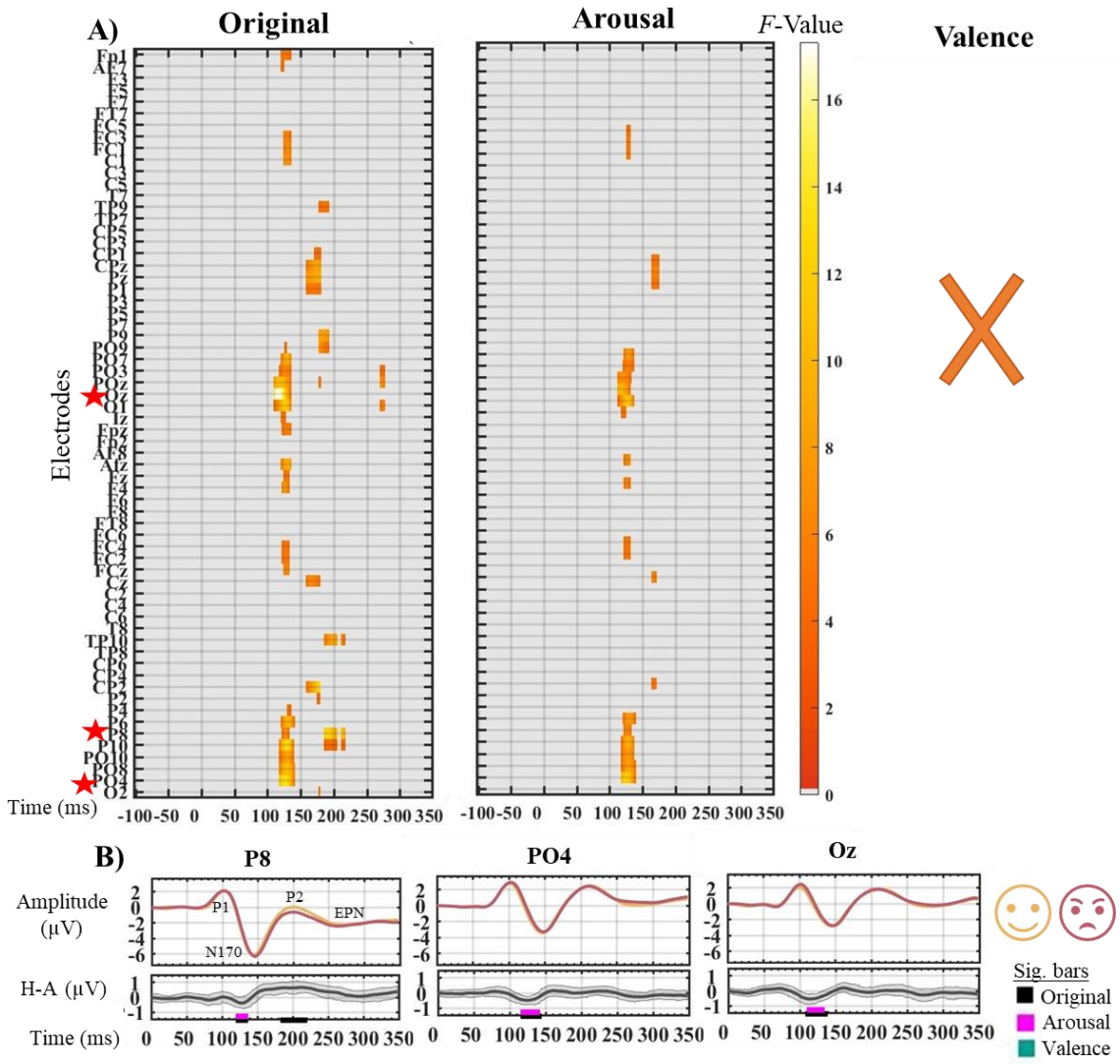
In the original model, happy and angry faces significantly differed before the N170, during the P1-N170 interval, on parietal and occipital electrodes (110-140ms; max at 116ms on Oz; $F(1, 79) = 17.33$, $p = .001$, [H-A] $\Delta\mu V = -0.54$; Figure 7; Appendix B Table 4), and frontal sites (120-134ms; max at 130ms on AFz; $F(1, 79) = 9.42$, $p = .001$, [H-A] $\Delta\mu V = 0.48$). This contrast was also significant on the N170-P2 from 158-216ms on midline central and midline posterior electrodes (max on CP2 at 178ms; $F(1, 79) = 12.66$, $p = .001$, [H-A] $\Delta\mu V = -0.36$), and on the P2 at lateral parietal sites (max at 188ms on P8; $F(1, 79) = 12.64$, $p = .001$, [H-A] $\Delta\mu V = 0.64$). Lastly, happy and angry faces briefly differed on the EPN, from 270-276ms on left parietal-occipital electrodes (max at 270ms on POz; $F(1, 79) = 10.56$, $p = .008$, $\Delta\mu V = -0.367$ [H-A]).

The arousal model was also significant during the P1-N170 interval from 112-138ms on parietal-occipital electrodes (max on PO4 at 124ms; $F(1, 79) = 12.12$, $p = .001$, [H-A] $\Delta\mu V = -0.48$) and frontal sites (max at 130ms on AFz; $F(1, 79) = 6.96$, $p = .001$, [H-A] $\Delta\mu V = 0.48$). Arousal also related to happy-angry differences from 164-174ms on midline central-parietal electrodes (max at Cz at 164ms; $F(1, 79) = 6.11$, $p = .001$, [H-A] $\Delta\mu V = -0.28$). The valence model did not reach significance with the correction for multiple comparisons.

Overall, happy and angry faces differed before the N170, as well as on the P2, and to a lesser extent the EPN. Arousal ratings related to happy-angry differences mainly before the N170, but also briefly later (164-174ms) on midline parietal electrodes.

Figure 7

Results from the happy and angry expression contrasts (p<.008).



Note. A) Plots representing the *happy and angry expression contrasts* for the original, arousal, and valence analyses (p<.008). Time in milliseconds is along the X axis of each plot, and electrodes are along the Y axis. Red stars beside electrode names indicate electrodes plotted in section B. The colour bar represents the F-Values of significant datapoints, where grey indicates insignificant datapoints. F-values are corrected using cluster mass correction for multiple comparisons. B) ERPs (top) and difference wave (bottom; happy-angry) on key electrodes. ERP waveforms elicited by happy faces are presented in yellow and anger in pink. On the difference wave plots, black significance bars indicate when electrodes were significant in the original analysis, bright pink bars indicate when the arousal analysis was significant, and blue bars indicate when the valence analysis was significant. Note the lack of blue bars due to a lack of

significance for the valence model. Confidence intervals on the difference wave plots were computed with 20% trimmed means and Bayesian bootstrapping at $\alpha = .008$.

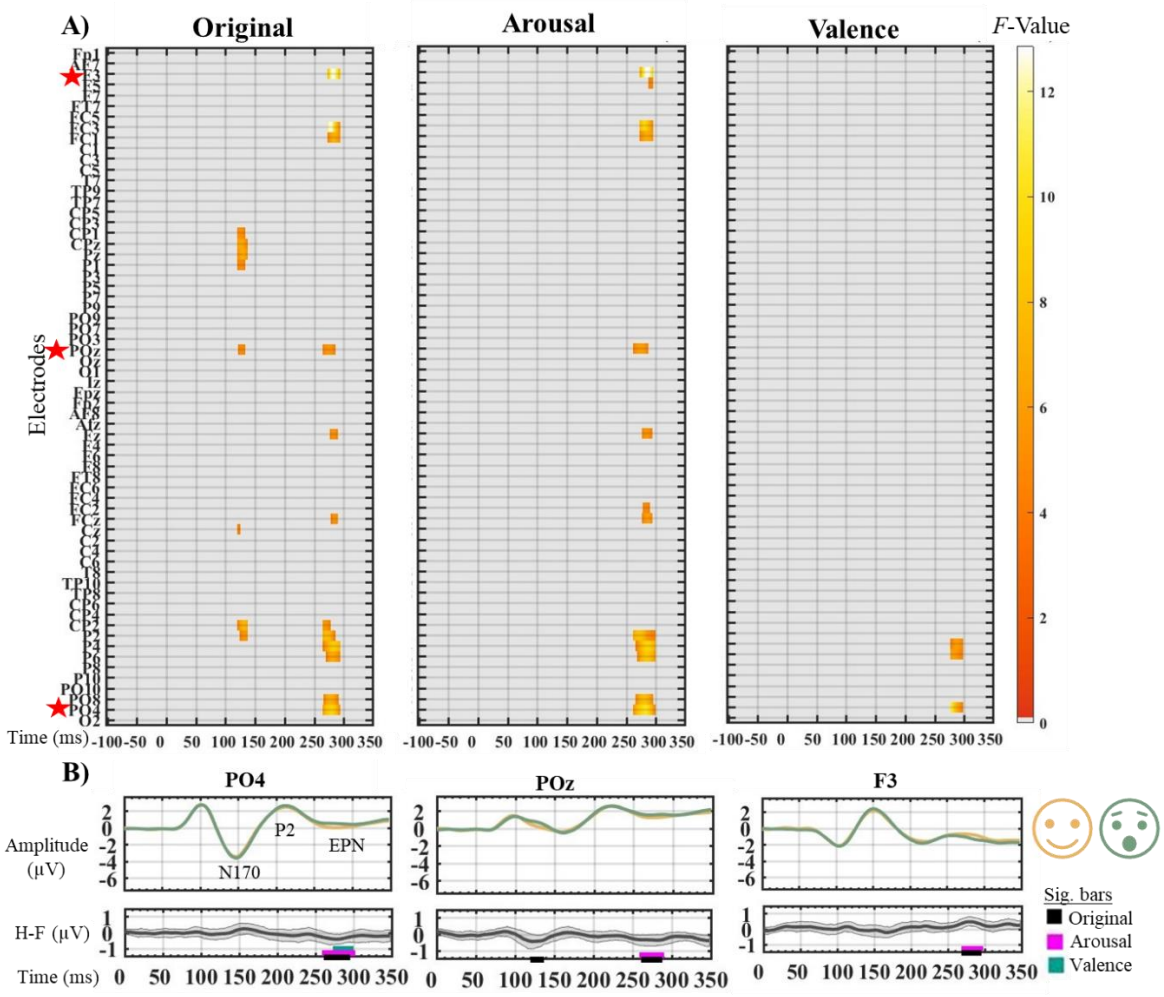
3.2.6 Happy-fearful expression contrasts

In the original model, happy and fearful expressions differed from 120-163ms on midline central and parietal sites (Figure 8; Appendix B Table 5; max on CP2 at 132ms; $F(1, 79) = 7.65$, $p = .001$, [H-F] $\Delta\mu V = -0.42$). They also differed on the EPN, from 264-292ms on right parietal-occipital sites (max at 278ms on PO4; $F(1, 79) = 9.38$, $p = .001$, [H-F] $\Delta\mu V = -0.39$) and left frontal electrodes (max on F3 at 282ms; $F(1, 79) = 12.87$, $p = .001$, [H-F] $\Delta\mu V = 0.48$). The arousal model was only significant on the EPN, from 262-294 on right parietal-occipital electrodes (max on PO4 at 282ms; $F(1, 79) = 10.39$, $p = .001$, [H-F] $\Delta\mu V = -0.39$) and on left frontal sites (max on F3 at 284ms; $F(1, 79) = 13.14$, $p = .001$, [H-F] $\Delta\mu V = 0.48$). This shows that EPN differences (in the emotion model) were related to arousal ratings. The valence model was also significant on the EPN, from 276-296ms on right parietal electrodes (max on PO4 at 276ms; $F(1, 79) = 10.97$, $p = .001$, [H-F] $\Delta\mu V = -0.39$).

Overall, happy and fearful faces predominantly differed on the EPN, with more negative amplitudes for happy than fearful faces. This result was related to both arousal and valence ratings.

Figure 8

Results from the happy and fearful expression contrasts (p<.008).



Note. A) Plots representing the *happy and fearful expression contrasts* for the original, arousal, and valence analyses (p<.008). Time in milliseconds is along the X axis of each plot, and electrodes are along the Y axis. Red stars beside electrode names indicate electrodes plotted in section B. The colour bar represents the F-Values of significant datapoints, where grey indicates insignificant datapoints. F-values are corrected using cluster mass correction for multiple comparisons. B) ERPs (top) and difference wave (bottom; happy-fear) on key electrodes. ERP waveforms elicited by happy faces are presented in yellow and fearful in green. On the difference wave plots, black significance bars indicate when electrodes were significant in the original analysis, bright pink bars indicate when the arousal analysis was significant, and blue bars indicate when the valence analysis was significant. Confidence intervals on the difference wave plots were computed with 20% trimmed means and Bayesian bootstrapping at $\alpha = .008$.

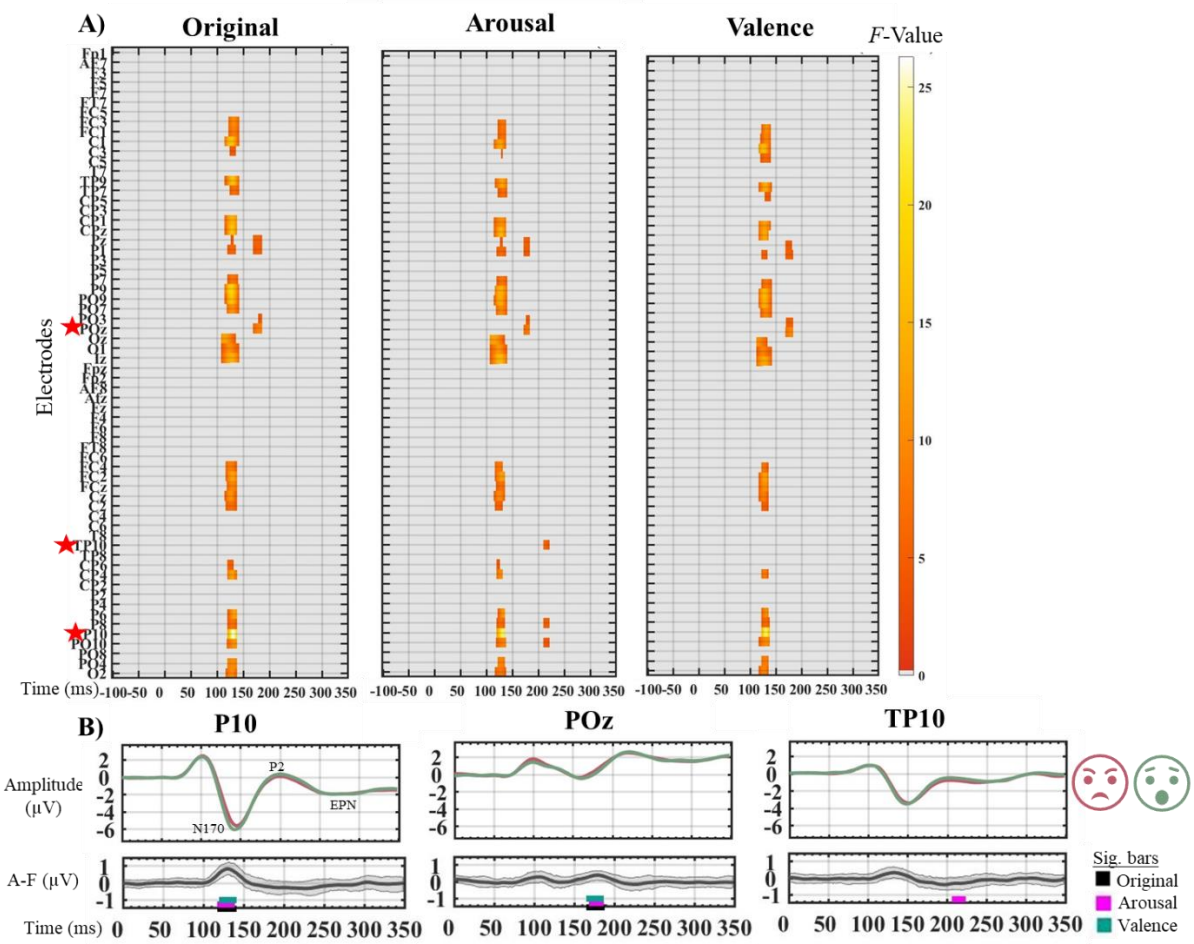
3.2.7 Angry-fearful expression contrasts

Angry and fearful faces revealed highly overlapping results for all three models, so results will be summarized (Figure 9; for more details, please see Appendix B Table 6). All analyses were significant before the N170 on frontal, temporal, central, parietal-occipital sites, from approximately 106-140ms (max on P10 at 130ms; $F(1, 79)_{original} = 26.30$, $p_{original} = .001$, [A-F] ΔμV = 0.83). Analyses were also significant following the N170, from approximately 168-184ms on left parietal-occipital electrodes (max at 180ms on POz; $F(1, 79)_{original} = 9.40$, $p_{original} = .001$, ΔμV = 0.39 [A-F]). The arousal analysis had an additional brief cluster of significance on right temporal and parietal sites from 210-220ms (max on TP10 at 210ms; $F(1, 79) = 6.08$, $p = .007$, ΔμV = -0.31 [A-F]).

Overall, angry and fearful faces differed during the P1-N170 and N170-P2 intervals, related to both arousal and valence ratings.

Figure 9

Results from the angry and fearful expression contrasts (p<.008).



Note. A) Plots representing the *angry and fearful expression contrasts* for the original (emotion), arousal, and valence analyses ($p<.008$). Plots were created in the LIMO toolbox. Time in milliseconds is along the X axis of each plot, and electrodes are along the Y axis. Red stars beside electrode names indicate electrodes plotted in section B. The colour bar represents the F-Values of significant datapoints, where grey indicates insignificant datapoints. F-values are corrected using cluster mass correction for multiple comparisons. B) ERPs (top) and difference wave (bottom; angry-fear) on key electrodes. ERP waveforms elicited by angry faces are presented in pink and fear in green. On the difference wave plots, black significance bars indicate when electrodes were significant in the original analysis, bright pink bars indicate when the arousal analysis was significant, and blue bars indicate when the valence analysis was significant. Confidence intervals on the difference wave plots were computed with 20% trimmed means and Bayesian bootstrapping at $\alpha = .008$.

Chapter 4
Discussion

The present study investigated the neural processing of four different categorical facial expressions (neutral, happy, anger, and fear) and sought to understand if this processing was related to the expression's perceived valence or arousal as previously hypothesized (Han et al., 2021; Itier & Durston, 2023; Mueller et al., Submitted; Schupp, Ohman, et al., 2004). Further, we extended previous research by: 1) conducting a full scalp Mass Univariate (MU) analysis to control for type I and II errors (Luck & Gaspelin, 2017), 2) enforcing foveal fixation on the nose with an eye tracker (Itier & Durston, 2023; Nemrodov et al., 2014), 3) obtaining stimulus-level ratings of arousal and valence for a within-subjects comparison with ERP data (as opposed to between-subjects comparisons in the extant literature; e.g., Almeida et al., 2016; Calvo, Marrero, et al., 2013; Li et al., 2022), and lastly 4) directly comparing fear and anger, which has only been done in a handful of studies (Almeida et al., 2016; Calvo, Marrero, et al., 2013; Herbert et al., 2013; Rossignol et al., 2005; Smith et al., 2013; Turano et al., 2017).

Based on the literature, we predicted a main effect of emotion on arousal ratings, driven by all expressions being more aroused than neutral. For valence ratings, we anticipated that happy faces would be rated as the most positive expression, followed by neutral, then fear and anger, which would not differ. For ERP data, we predicted more negative N170, P2, and EPN amplitudes for fearful and angry expressions compared to happy and neutral faces, being maximal between 180-200ms as seen in recent MU analyses (Durston & Itier, 2021, Itier & Durston, 2023). We also anticipated more negative N170 amplitudes for fearful than angry expressions. We further predicted that early effects (N170 and P2) would be related to perceived arousal, whereas later effects (EPN) would be related to both arousal and valence.

Our behavioural results partially deviated from our predictions. For arousal, we found that fearful faces were rated as more aroused than other expressions, which is a novel finding. Most previous work has shown fear to be equal or lower on arousal compared to anger and happiness (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Goeleven et al., 2008; Herbert et al., 2013). This new result may be due to our hybrid database approach, combining four face databases to ensure generalizable results (Adolph & Alpers, 2010), or to our large sample (N=80), compared to an average of 22 participants used by others (computed from Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013; Herbert et al., 2013). Only two other large-scale multi-database investigations have been conducted, but one used only female participants (Goeleven et al., 2008), and the other focused on how the faces made the participants feel, as opposed to how the participants perceived

the expressions (Sutton et al., 2019). Further, it is unlikely that this novel result is due to our arousal prompts (i.e., "how affectively arousing is this face"), as our results deviate even from studies using near identical wording (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013). We obtained all other expected arousal results, including equivalent happy and angry arousal ratings (Calvo, Marrero, et al., 2013; Herbert et al., 2013). We deemed this finding as evidence that participants were interpreting the prompts as expected. Thus, our results likely deviate from previous work due to our sample being roughly four times larger than extant studies, and in consequence being more robust and having higher power. For valence, our results replicated those of Calvo and colleagues, with happy being the most positive expression, followed by neutral, then fearful, and lastly, angry faces being the most negative (Calvo et al., 2016; Calvo, Gutiérrez-García, et al., 2013; Calvo, Marrero, et al., 2013). It is noteworthy that others have found no difference in valence ratings for fear and anger (Herbert et al., 2013), although the present study included many more participants, so previous work may have been underpowered. Further, the perceived arousal and valence of threat-related expressions may be highly subjective, and impacted by many subject-level factors, like biological sex (Stevens & Hamann, 2012; Thompson & Voyer, 2014), or anxiety levels (Honk et al., 2001; Rossignol et al., 2005), potentially leading to the divergent results we obtained and inconsistencies in the field. In fact, we found large variations in arousal ratings, suggesting differences in the perception of expressions from person to person. Thus, more large sample multi-database facial expression rating experiments considering individual differences are needed.

Moving on to ERP data, we found that all emotion contrasts were related to valence, arousal, or both. This suggests that the inconsistencies in the ERP literature could be related to participants' perception of each individual face stimuli. This conclusion is more probable than systematic subject-level individual differences (e.g., participant X "on average" rating happy as high on arousal). We conducted an exploratory correlation analysis, which looked at how each participant's overall average (not trial level) arousal and valence ratings for each expression correlated with their brain activity to that expression. This analysis only revealed sparse (and sometimes extremely early) effects for a handful of expressions (Appendix C Figure 1). These results do not align with our stimulus-level arousal and valence results reported above. Thus, researchers must consider participants' stimulus-level perceptual experiences to aid in the replicability of emotion-processing studies. However, this study collected arousal and valence ratings after the ERP recordings, so perception of the faces may have varied during the actual ERP trials. Replicating the present research on a true trial basis and utilizing other statistical methods to partition out the variance associated with perceived arousal and valence, is critical for accounts of facial expression perception and their neural correlates.

Diving into specific ERP components, the N170 was by far the most impacted by emotion differences and arousal and valence ratings. Historically, this component is considered an index of holistic face perception, in other words piecing together features into a gestalt whole (Bentin et al., 1996; Itier & Taylor, 2004; Rossion & Jacques, 2011; Schyns et al., 2007). However, emotion effects have been seen on this component for decades (Batty & Taylor, 2003; see Schindler & Bublatzky, 2020 for review). The P1-N170 interval, the downstroke part towards the N170 peak, is sensitive to diagnostic features of a facial expression (i.e., wide eyes for fear; Schyns et al., 2007) and the upstroke following the N170 has been claimed to be involved in emotion extraction (Han et al., 2021; Itier & Durston, 2023; Mueller et al., submitted). Recent behavioural work has found that the structural action units engaged in facial expressions convey arousal and valence (Liu et al., 2022). Thus, our N170 emotion effects and their relationship between arousal and valence may indicate the structural encoding of the features which convey valence or arousal. These features are different for every expression (Liu et al., 2022), further explaining why we do not see consistent modulation by arousal and valence on the N170 across contrasts.

Further, we found that the N170 was related to valence in the neutral-angry, neutral-fear, and angry-fearful contrasts. Angry and fearful expressions elicited larger N170s than neutral faces, and fearful faces elicited earlier and larger N170s than angry ones. These findings align with accounts that the N170 is sensitive to valence (Calvo & Beltrán, 2013), although this seems threat-specific. N170 amplification for threat-related expressions has been well documented (Schindler & Bublatzky, 2020). Specifically, these effects are often interpreted as driven by amygdala projections to the fusiform, amplifying activity in the neural generators of the N170 (Herrington et al., 2011; Krolak-Salmon et al., 2004; Méndez-Bértolo et al., 2016). Some have shown the amygdala is sensitive to perceived valence (Kim et al., 2017) and has a larger BOLD response to fear than to other expressions (Whalen et al., 2001). Fearful expressions are often confused for surprise and thus likely involve more neural recruitment to decipher the potentially ambiguous valence than other faces (Kim et al., 2017; Zhao et al., 2017). Therefore, it is possible that when viewing threat-related expressions, the amygdala is involved in deciphering the valence of the other person, then conveying this information to the visual regions, which augments the N170 (but see Lin et al., 2020 for an opposite account). In conjunction with stimulus and trial level arousal and valence ratings, more intracranial work is needed to understand this potential mechanism.

The N170 was also sensitive to arousal in contrasts involving angry expressions (i.e., neutral-angry, happy-angry, and angry-fearful expression contrasts). Fearful and happy expressions elicited more negative N170 amplitudes than angry faces before the N170 peak, relating to arousal. Angry expressions elicited later and more negative N170 peaks than neutral expressions, and again, this effect was related to arousal. This is in line with computational (Li et al., 2022) and experimental (Almeida et al., 2016)

evidence suggesting that arousal is extracted during the N170 time window. Our data suggest that arousal extraction on the N170 is specific to angry faces. As mentioned, emotion effects on the N170 are theorized to be related to amygdala projections. Previous work has suggested the amygdala is sensitive to stimulus arousal regardless of the facial expression (Lin et al., 2020). Thus, given that we found marked differences between emotions on the N170, it is unlikely that the amygdala is involved in our present anger-specific results. It is more plausible that this effect is due to structural components of the face (but see Bruchmann et al., 2020, 2023). The N170 is impacted by the configuration of the eye region (Itier, 2015; Leppänen et al., 2008; Nemrodov et al., 2014; Parkington & Itier, 2018; Winward et al., 2022), and this region conveys arousal associated with an angry face but not other expressions (Liu et al., 2022; but see Leppänen et al., 2008 and Whalen et al., 2001 who suggest arousal is conveyed by fearful eyes) Thus, this arousal effect is likely contrasting the arousal conveyed by furrowing and compressing the eye region in angry faces, to the neutral or wide eyes in other expressions.

Our result that participants' perceived arousal and valence modulate the N170 suggests that the inconsistencies in the field may be related to these stimulus level variations. In an exploratory analysis (Appendix C Figure 1) we found that participants' average arousal and valence ratings for each expression did not correlate with the expression ERP amplitudes on the N170, regardless of the type of expression. Thus, the present results are related to stimulus-level ratings rather than systematic individual differences in perception of emotions. This is not surprising, as many structural and emotional variations exist within emotion categories (Ekman, 1965, 1993; Tracy & Robins, 2007) and across different databases (Adolph & Alpers, 2010). Studies investigating the impact of emotional expressions on the N170 should begin using large sets of expressions from multiple datasets (Adolph & Alpers, 2010; Sutton et al., 2019) or randomly computer-generated sources (e.g., Liu et al., 2022), in addition to taking stimulus or trial level ratings of perceived arousal and valence. In other words, the field must start considering stimulus level variations in behavioural and ERP responses to emotional expressions, instead of averaging data across all stimuli in an emotion category. This will improve the generalizability of results and further our understanding of the interactions between structural encoding and emotion extraction that occurs on the N170.

On the P2, we found that angry expressions elicited less positive P2 components than happy and neutral expressions. This finding has been reported by others using expressions of anger (Han et al., 2021; Mueller et al., submitted) and fear (Durston & Itier, 2021; Itier & Durston, 2023). These studies have interpreted their findings as related to the emotional content of the stimulus. We now refute this proposition, as emotion extraction (i.e. arousal and valence) appears to occur earlier, around the N170, at least for threat-related expressions. Previous work has suggested that the P2 is sensitive to attended vs

unattended stimuli (Kanske et al., 2011) and typical vs atypical faces (Kloth et al., 2017; Schweinberger & Neumann, 2016; Winward et al., 2022). Thus, it is possible that the present P2 effects index emotion-irrelevant attentional mechanisms. Previous work has shown that P2 effects of emotion (namely fear and anger) do not interact with external task demands (Durston & Itier, 2021; Itier & Durston, 2023; Mueller et al., submitted). Thus, if the P2 is indicating emotion-irrelevant attentional processes, these processes must be bottom-up such as spontaneous attentional capture related to an angry face, which is infrequent and atypical in our daily life (~8% of expressions; Calvo et al., 2014), as opposed to top-down mechanisms driven by external demands (e.g., tasks). Regardless, more research is needed to understand the underlying mechanisms behind emotion effects on the P2, as less than 18% of emotion expression studies analyze it (Schindler & Bublatzky, 2020).

The only rating-modulated effect revealed around the P2 was in the happy-neutral contrast, where these expressions differed from 180-200ms (N170 upstroke towards the P2) only in the valence analysis (and only on right posterior electrodes). No significant difference was seen in this window in the original model not considering ratings, so this finding suggests a unique modulation of neural activity by perceived valence above and beyond the structural elements of the faces. A majority of previous studies (14 out of 15 studies as per Schindler & Bublatzky's 2020 review) found no difference between happy and neutral faces on the P2 (also see Durston & Itier, 2021; Han et al., 2021). Traditional studies consider emotions as categories, averaging across all stimuli within each category instead of considering participants' perceptions of each face. This approach could be the source of null results previously reported. However, the present finding only spans 20ms, and has *F*-values below 10, so it may be a type I error. Thus, full epoch analyses are required, while considering stimuli level valence ratings, to understand this effect.

Lastly, only two contrasts differed on the EPN. Happy faces elicited more negative EPN amplitudes than fearful or neutral faces. The fear-happy result is unexpected. Previous MU analysis studies have suggested that happy and fearful expressions do not differ on the EPN (Durston & Itier, 2021; Itier & Durston, 2023). The present fear-happy result is rather small; thus, the previous MU analyses may have been underpowered to reveal the effect. On the other hand, although we did not predict happy-neutral differences on the EPN, many others have shown more negative amplitudes for happy than neutral faces (Calvo, Marrero, et al., 2013; Calvo & Beltrán, 2013; Rellecke et al., 2012). Most important to the present study, these EPN results were related to arousal and valence ratings, as predicted (Li et al., 2022). Previous work has suggested that the EPN is involved in determining the intensity and arousal level of an expression (Calvo & Beltrán, 2013; Olofsson et al., 2008), which may be related to the configuration of the mouth region (open vs closed; Langeslag & van Strien, 2018). Happy faces with open

mouths, like the ones in the present study, have more extreme arousal and valence ratings than those with closed mouths, and have more negative EPNs (Langeslag & van Strien, 2018). It is possible that differences in mouth configuration across studies could be linked to past inconsistencies. Further, our analysis included stimulus-level ratings of arousal and valence and likely captured the variance associated with the size of smiles from face to face, leading to this effect.

It is interesting that no other contrasts elicited significant differences on the EPN. Historically, the EPN has been "the" attention and emotion perception component. The EPN is considered sensitive to emotional arousal and valence (Calvo & Beltrán, 2013; Olofsson et al., 2008; Schupp, Junghöfer, et al., 2004) and is augmented when perceiving emotions in faces, scenes, and words (Schacht & Sommer, 2009; Schupp, Junghöfer, et al., 2004; Schupp, Ohman, et al., 2004). If the EPN is a general attention and emotion-related component, we would expect a significant difference between threat-related and neutral expressions on this component and a relationship with arousal and valence ratings. However, we did not find the anticipated EPN effect for fearful or angry compared to neutral expressions, opposing a bulk of the previous literature (Calvo & Beltrán, 2013; Mueller et al., submitted; Schupp, Ohman, et al., 2004; Wronka & Walentowska, 2011; see Schindler & Bublatzky, 2020 for a review). The present study used high methodological and statistical controls for error, such as MU statistics (Luck & Gaspelin, 2017), a large sample of 80 participants (average N = 33 in ERP emotion studies; Schindler & Bublatzky, 2020), and gaze-contingent procedures (Neath & Itier, 2015; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Itier & Preston, 2018). Previous work employing gaze-contingent and MU statistics found limited emotional effects on the EPN (Durston & Itier, 2021; Hudson et al., 2021; Itier & Durston, 2023; Mueller et al., submitted). Thus, augmented EPNs reported in previous studies may be a type I error.

Although the present study makes leaps in the advancement of understanding the neural encoding of facial expressions, it has limitations. First, our arousal and valence ratings were stimulus-level, not trial-level. This means that participants rated faces on arousal and valence after their ERPs were recorded in a separate task. Future research should get participants to rate expressions after each trial as the ERPs are recorded. Second, the present analysis touches onto multilevel approaches, where we enter different levels of analysis into the models (categories vs stimuli ratings). However, a true multilevel analysis with variance associated with each level (e.g., trial level, stimulus level, category level, and participant level) would be ideal. Only one group has begun using multilevel approaches in ERP data (Volpert-Esmond et al., 2021), although their method is only on a few electrodes and time windows, so there is much room for growth. Further, the present study only included static images, yet affective and cognitive neuroscience domains are moving towards dynamic visual stimuli (Grootswagers et al., 2020; Recio et al., 2014). Although we used multiple stimuli databases and highly controlled stimuli, our work should be replicated

using dynamic stimuli to determine the generalizability of the present effects. Lastly, our sample was culturally diverse, with only a third of our participants being the same race as our stimuli (i.e., Caucasian). This is both a positive and a negative. There is a wealth of literature surrounding how race impacts the perception of faces (i.e., other-race-effect; Colombatto & McCarthy, 2017; O'toole et al., 1994; Rhodes et al., 2009) and emotions (Hu et al., 2017; Lee et al., 2008). However, we do not believe this undermines our results, as applicants who were new to North America were not eligible to participate, and our multicultural sample ensures generalizability of results.

Despite these limitations, the present study is one of the first of its kind to conduct robust data-driven full-scalp analyses on a large sample (N = 80) of participants. This is also the first study to consider the relationship between arousal and valence ratings and ERP waveforms at the trial level, making it an important contribution to the field. The present results suggest that no singular ERP component is sensitive to valence or arousal, as previously discussed (Almeida et al., 2016; Calvo & Beltrán, 2013; Calvo & Nummenmaa, 2016; Han et al., 2021). Thus, it is critical that future research considers the relationship between valence/arousal ratings and ERP amplitudes at the stimulus, trial, and individual levels to fully understand when our brain extracts affective information from faces.

References

Adolph, D., & Alpers, G. W. (2010). Valence and Arousal: A Comparison of Two Sets of Emotional Facial Expressions. *The American Journal of Psychology*, *123*(2), 209–219. https://doi.org/10.5406/amerjpsyc.123.2.0209

Almeida, P. R., Ferreira-Santos, F., Chaves, P. L., Paiva, T. O., Barbosa, F., & Marques-Teixeira, J. (2016). Perceived arousal of facial expressions of emotion modulates the N170, regardless of emotional category: Time domain and time–frequency dynamics. *International Journal of Psychophysiology*, *99*, 48–56. https://doi.org/10.1016/j.ijpsycho.2015.11.017

Atkinson, A. P., & Smithson, H. E. (2020). The impact on emotion classification performance and gaze behavior of foveal versus extrafoveal processing of facial features. *Journal of Experimental Psychology: Human Perception and Performance*, *46*, 292–312. https://doi.org/10.1037/xhp0000712

Batty, M., & Taylor, M. J. (2003). Early processing of the six basic facial emotional expressions. *Cognitive Brain Research*, *17*(3), 613–620. https://doi.org/10.1016/S0926-6410(03)00174-5

Bayless, S. J., Glover, M., Taylor, M. J., & Itier, R. J. (2011). Is it in the eyes? Dissociating the role of emotion and perceptual features of emotionally expressive faces in modulating orienting to eye gaze. *Visual Cognition*, *19*(4), 483–510. https://doi.org/10.1080/13506285.2011.552895

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological Studies of Face Perception in Humans. *Journal of Cognitive Neuroscience*, *8*(6), 551–565. https://doi.org/10.1162/jocn.1996.8.6.551

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*(3), 305–327. https://doi.org/10.1111/j.2044-8295.1986.tb02199.x

Bruchmann, M., Mertens, L., Schindler, S., & Straube, T. (2023). Potentiated early neural responses to fearful faces are not driven by specific face parts. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-31752-z

Bruchmann, M., Schindler, S., & Straube, T. (2020). The spatial frequency spectrum of fearful faces modulates early and mid-latency ERPs but not the N170. *Psychophysiology*, *57*(9), e13597. https://doi.org/10.1111/psyp.13597

Calvo, M. G., Avero, P., Fernández-Martín, A., & Recio, G. (2016). Recognition thresholds for static and dynamic emotional faces. *Emotion*, *16*(8), 1186–1200. https://doi.org/10.1037/emo0000192

Calvo, M. G., & Beltrán, D. (2013). Recognition advantage of happy faces: Tracing the neurocognitive processes. *Neuropsychologia*, *51*(11), 2051–2061. https://doi.org/10.1016/j.neuropsychologia.2013.07.010

Calvo, M. G., Gutiérrez-García, A., Avero, P., & Lundqvist, D. (2013). Attentional mechanisms in judging genuine and fake smiles: Eye-movement patterns. *Emotion (Washington, D.C.)*, *13*(4), 792–802. https://doi.org/10.1037/a0032317

Calvo, M. G., Gutiérrez-García, A., Fernández-Martín, A., & Nummenmaa, L. (2014). Recognition of Facial Expressions of Emotion is Related to their Frequency in Everyday Life. *Journal of Nonverbal Behavior*, *38*(4), 549–567. https://doi.org/10.1007/s10919-014-0191-3

Calvo, M. G., Marrero, H., & Beltrán, D. (2013). When does the brain distinguish between genuine and ambiguous smiles? An ERP study. *Brain and Cognition*, *81*(2), 237–246. https://doi.org/10.1016/j.bandc.2012.10.009

Calvo, M. G., & Nummenmaa, L. (2016). Perceptual and affective mechanisms in facial expression recognition: An integrative review. *Cognition & Emotion*, *30*(6), 1081–1106. https://doi.org/10.1080/02699931.2015.1049124

Carroll, J. M., & Russell, J. A. (1996). Do facial expressions signal specific emotions? Judging emotion from the face in context. *Journal of Personality and Social Psychology*, *70*(2), 205–218. https://doi.org/10.1037/0022-3514.70.2.205

Colombatto, C., & McCarthy, G. (2017). The Effects of Face Inversion and Face Race on the P100 ERP. *Journal of Cognitive Neuroscience*, *29*(4), 664–676. https://doi.org/10.1162/jocn_a_01079

Connor, K. M., Davidson, J. R. T., Churchill, L. E., Sherwood, A., Weisler, R. H., & Foa, E. (2000). Psychometric properties of the Social Phobia Inventory (SPIN): New self-rating scale. *The British Journal of Psychiatry*, *176*(4), 379–386. https://doi.org/10.1192/bjp.176.4.379

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Durston, A. J., & Itier, R. J. (2021). The early processing of fearful and happy facial expressions is independent of task demands – Support from mass univariate analyses. *Brain Research*, *1765*, 147505. https://doi.org/10.1016/j.brainres.2021.147505

Ebner, N. C., Riediger, M., & Lindenberger, U. (2010). FACES—A database of facial expressions in young, middle-aged, and older women and men: Development and validation. *Behavior Research Methods*, *42*(1), 351–362. https://doi.org/10.3758/BRM.42.1.351

Eisenbarth, H., & Alpers, G. W. (2011). Happy mouth and sad eyes: Scanning emotional facial expressions. *Emotion*, *11*(4), 860–865. https://doi.org/10.1037/a0022758

Ekman, P. (1965). Differential communication of affect by head and body cues. *Journal of Personality and Social Psychology*, *2*, 726–735. https://doi.org/10.1037/h0022736

Ekman, P. (1993). Facial expression and emotion. *The American Psychologist*, *48*(4), 384–392. https://doi.org/10.1037//0003-066x.48.4.384

Gerber, A. J., Posner, J., Gorman, D., Colibazzi, T., Yu, S., Wang, Z., Kangarlu, A., Zhu, H., Russell, J., & Peterson, B. S. (2008). An affective circumplex model of neural systems subserving valence, arousal, and cognitive overlay during the appraisal of emotional faces. *Neuropsychologia*, *46*(8), 2129–2139. https://doi.org/10.1016/j.neuropsychologia.2008.02.032

Goeleven, E., De Raedt, R., Leyman, L., & Verschuere, B. (2008). The Karolinska Directed Emotional Faces: A validation study. *Cognition and Emotion*, *22*(6), 1094–1118. https://doi.org/10.1080/02699930701626582

Grootswagers, T., Kennedy, B. L., Most, S. B., & Carlson, T. A. (2020). Neural signatures of dynamic emotion constructs in the human brain. *Neuropsychologia*, *145*, 106535. https://doi.org/10.1016/j.neuropsychologia.2017.10.016

Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-Related Potentials, Emotion, and Emotion Regulation: An Integrative Review. *DEVELOPMENTAL NEUROPSYCHOLOGY*, *35*(2), 129–155. https://doi.org/10.1080/87565640903526504

Han, S., Hu, J., Li, W., Zhao, S., Chen, M., Xu, P., & Luo, Y. (2021). From structure to concepts: The two stages of facial expression recognition. *Neuropsychologia*, *150*, 107700. https://doi.org/10.1016/j.neuropsychologia.2020.107700

Herbert, C., Sfaerlea, A., & Blumenthal, T. (2013). Your emotion or mine: Labeling feelings alters emotional face perception—an ERP study on automatic and intentional affect labeling. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00378

Herrington, J. D., Taylor, J. M., Grupe, D. W., Curby, K. M., & Schultz, R. T. (2011). Bidirectional communication between amygdala and fusiform gyrus during facial recognition. *NeuroImage*, *56*(4), 2348–2355. https://doi.org/10.1016/j.neuroimage.2011.03.072

Hinojosa, J. A., Mercado, F., & Carretié, L. (2015). N170 sensitivity to facial expression: A meta-analysis. *Neuroscience & Biobehavioral Reviews*, *55*, 498–509. https://doi.org/10.1016/j.neubiorev.2015.06.002

Honk, J. V., Tuiten, A., de Haan, E., vann de Hout, M., & Stam, H. (2001). Attentional biases for angry faces: Relationships to trait anger and anxiety. *Cognition and Emotion*, *15*(3), 279–297. https://doi.org/10.1080/02699930126112

Hu, C. S., Wang, Q., Han, T., Weare, E., & Fu, G. (2017). Differential emotion attribution to neutral faces of own and other races. *Cognition and Emotion*, *31*(2), 360–368. https://doi.org/10.1080/02699931.2015.1092419

Hudson, A. (2022). *Examining the neural, behavioural, and social responses associated with affective self-referential processing in adults and children.* [Doctoral Thesis, University of Waterloo]. https://uwspace.uwaterloo.ca/handle/10012/18432

Hudson, A., Durston, A. J., McCrackin, S. D., & Itier, R. J. (2021). Emotion, Gender and Gaze Discrimination Tasks do not Differentially Impact the Neural Processing of Angry or Happy Facial Expressions—A Mass Univariate ERP Analysis. *Brain Topography*, *34*(6), 813–833. https://doi.org/10.1007/s10548-021-00873-x

Itier, R. J. (2015). Attention to eyes in face perception. In *The handbook of attention* (pp. 369–387). Boston Review.

Itier, R. J., & Durston, A. J. (2023). Mass-univariate analysis of scalp ERPs reveals large effects of gaze fixation location during face processing that only weakly interact with face emotional expression. *Scientific Reports*, *13*(1), Article 1. https://doi.org/10.1038/s41598-023-44355-5

Itier, R. J., & Taylor, M. J. (2004). N170 or N1? Spatiotemporal Differences between Object and Face Processing Using ERPs. *Cerebral Cortex*, *14*(2), 132–142. https://doi.org/10.1093/cercor/bhg111

James, W. (1884). IWHAT IS AN EMOTION? *Mind*, *9*(34), 188–205.

Kanske, P., Plitschka, J., & Kotz, S. A. (2011). Attentional orienting towards emotion: P2 and N400 ERP effects. *Neuropsychologia*, *49*(11), 3121–3129. https://doi.org/10.1016/j.neuropsychologia.2011.07.022

Keltner, D., Sauter, D., Tracy, J., & Cowen, A. (2019). Emotional Expression: Advances in Basic Emotion Theory. *Journal of Nonverbal Behavior*, *43*(2), 133–160. https://doi.org/10.1007/s10919-019-00293-3

Kim, M. J., Mattek, A. M., Bennett, R. H., Solomon, K. M., Shin, J., & Whalen, P. J. (2017). Human Amygdala Tracks a Feature-Based Valence Signal Embedded within the Facial Expression of Surprise. *Journal of Neuroscience*, *37*(39), 9510–9518. https://doi.org/10.1523/JNEUROSCI.1375-17.2017

Kline, R. B. (1998). *Principles and practice of structural equation modeling*. Guilford Press.

Kloth, N., Rhodes, G., & Schweinberger, S. R. (2017). Watching the brain recalibrate: Neural correlates of renormalization during face adaptation. *NeuroImage*, *155*, 1–9. https://doi.org/10.1016/j.neuroimage.2017.04.049

Krolak-Salmon, P., Hénaff, M.-A., Vighetto, A., Bertrand, O., & Mauguière, F. (2004). Early Amygdala Reaction to Fear Spreading in Occipital, Temporal, and Frontal Cortex: A Depth Electrode ERP Study in Human. *Neuron*, *42*(4), 665–676. https://doi.org/10.1016/S0896-6273(04)00264-8

Langeslag, S. J. E., & van Strien, J. W. (2018). Early visual processing of snakes and angry faces: An ERP study. *Brain Research*, *1678*, 297–303. https://doi.org/10.1016/j.brainres.2017.10.031

Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H. J., Hawk, S. T., & van Knippenberg, A. (2010). Presentation and validation of the Radboud Faces Database. *Cognition and Emotion*, *24*(8), 1377–1388. https://doi.org/10.1080/02699930903485076

Lee, K. U., Khang, H. S., Kim, K. T., Kim, Y. J., Kweon, Y.-S., Shin, Y.-W., Kwon, J. S., Ho, S.-H., Garfinkel, S. N., Chae, J.-H., & Liberzon, I. (2008). Distinct processing of facial emotion of own-race versus other-race. *NeuroReport*, *19*(10), 1021. https://doi.org/10.1097/WNR.0b013e3283052df2

Lee, M. D., & Wagenmakers, E. J. (2014). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.

Leppänen, J. M., Hietanen, J. K., & Koskinen, K. (2008). Differential early ERPs to fearful versus neutral facial expressions: A response to the salience of the eyes? *Biological Psychology*, *78*(2), 150–158. https://doi.org/10.1016/j.biopsycho.2008.02.002

Levenson, M. R., Kiehl, K. A., & Fitzpatrick, C. M. (1995). Assessing psychopathic attributes in a noninstitutionalized population. *Journal of Personality and Social Psychology*, *68*(1), 151–158. https://doi.org/10.1037//0022-3514.68.1.151

Li, Y., Zhang, M., Liu, S., & Luo, W. (2022). EEG decoding of multidimensional information from emotional faces. *NeuroImage*, *258*, 119374. https://doi.org/10.1016/j.neuroimage.2022.119374

Lin, H., Müller-Bardorff, M., Gathmann, B., Brieke, J., Mothes-Lasch, M., Bruchmann, M., Miltner, W. H. R., & Straube, T. (2020). Stimulus arousal drives amygdalar responses to emotional expressions across sensory modalities. *Scientific Reports*, *10*(1), 1898. https://doi.org/10.1038/s41598-020-58839-1

Liu, M., Duan, Y., Ince, R. A. A., Chen, C., Garrod, O. G. B., Schyns, P. G., & Jack, R. E. (2022). Facial expressions elicit multiplexed perceptions of emotion categories and dimensions. *Current Biology*, *32*(1), 200-209.e6. https://doi.org/10.1016/j.cub.2021.10.035

Luck, S. J., & Gaspelin, N. (2017). How to Get Statistically Significant Effects in Any ERP Experiment (and Why You Shouldn't). *Psychophysiology*, *54*(1), 146–157. https://doi.org/10.1111/psyp.12639

Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: A free stimulus set of faces and norming data. *Behavior Research Methods*, *47*(4), 1122–1135. https://doi.org/10.3758/s13428-014-0532-5

Méndez-Bértolo, C., Moratti, S., Toledano, R., Lopez-Sosa, F., Martínez-Alvarez, R., Mah, Y. H., Vuilleumier, P., Gil-Nagel, A., & Strange, B. A. (2016). A fast pathway for fear in human amygdala. *Nature Neuroscience*, *19*(8), Article 8. https://doi.org/10.1038/nn.4324

Mueller, C., Durston, A. J., & Itier, R. J. (Submitted). *Angry and happy expressions are processed independent of priming context and task demands—A Mass Univariate ERP Analysis.* [Submitted to Brain Research].

Neath, K. N., & Itier, R. J. (2015). Fixation to features and neural processing of facial expressions in a gender discrimination task. *Brain and Cognition*, *99*, 97–111. https://doi.org/10.1016/j.bandc.2015.05.007

Neath-Tavares, K. N., & Itier, R. J. (2016). Neural processing of fearful and happy facial expressions during emotion-relevant and emotion-irrelevant tasks: A fixation-to-feature approach. *Biological Psychology*, *119*, 122–140. https://doi.org/10.1016/j.biopsycho.2016.07.013

Nemrodov, D., Anderson, T., Preston, F. F., & Itier, R. J. (2014). Early sensitivity for eyes within faces: A new neuronal account of holistic and featural processing. *NeuroImage*, *97*, 81–94. https://doi.org/10.1016/j.neuroimage.2014.04.042

Ohman, A. (2009). Of snakes and faces: An evolutionary perspective on the psychology of fear. *Scandinavian Journal of Psychology*, *50*(6), 543–552. https://doi.org/10.1111/j.1467-9450.2009.00784.x

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology*, *77*(3), 247–265. https://doi.org/10.1016/j.biopsycho.2007.11.006

O'toole, A. J., Deffenbacher, K. A., Valentin, D., & Abdi, H. (1994). Structural aspects of face recognition and the other-race effect. *Memory & Cognition*, *22*(2), 208–224. https://doi.org/10.3758/BF03208892

Parkington, K. B., & Itier, R. J. (2018). One versus two eyes makes a difference! Early face perception is modulated by featural fixation and feature context. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *109*, 35–49. https://doi.org/10.1016/j.cortex.2018.08.025

Patrick, C. J. (2010). *Operationalizing the Triarchic Conceptualization of Psychopathy: Preliminary* [Unpublished Manual].

Patrick, C. J., Fowles, D. C., & Krueger, R. F. (2009). Triarchic conceptualization of psychopathy: Developmental origins of disinhibition, boldness, and meanness | Development and

Psychopathology | Cambridge Core. *Development and Psychopathology*, *21*(3), 913–938. https://doi.org/10.1017/S0954579409000492

Pernet, C. R., Chauveau, N., Gaspar, C., & Rousselet, G. A. (2011). LIMO EEG: A Toolbox for Hierarchical LInear MOdeling of ElectroEncephaloGraphic Data. *Computational Intelligence and Neuroscience*, *2011*, 831409. https://doi.org/10.1155/2011/831409

Pernet, C. R., Martinez-Cancino, R., Truong, D., Makeig, S., & Delorme, A. (2021). From BIDS-Formatted EEG Data to Sensor-Space Group Results: A Fully Reproducible Workflow With EEGLAB and LIMO EEG. *Frontiers in Neuroscience*, *14*, 610388. https://doi.org/10.3389/fnins.2020.610388

Qiu, R., Wang, H., & Fu, S. (2017). N170 Reveals the Categorical Perception Effect of Emotional Valence. *Frontiers in Psychology*, *8*, 2056. https://doi.org/10.3389/fpsyg.2017.02056

Recio, G., Schacht, A., & Sommer, W. (2014). Recognizing dynamic facial expressions of emotion: Specificity and intensity effects in event-related brain potentials. *Biological Psychology*, *96*, 111–125. https://doi.org/10.1016/j.biopsycho.2013.12.003

Ree, M., French, D., MacLeod, C., & Locke, V. (2008). Distinguishing Cognitive and Somatic Dimensions of State and Trait Anxiety: Development and Validation of the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA). *Behavioural and Cognitive Psychotherapy*, *36*, 313–332. https://doi.org/10.1017/S1352465808004232

Rellecke, J., Sommer, W., & Schacht, A. (2012). Does processing of emotional facial expressions depend on intention? Time-resolved evidence from event-related brain potentials. *Biological Psychology*, *90*(1), 23–32. https://doi.org/10.1016/j.biopsycho.2012.02.002

Rellecke, J., Sommer, W., & Schacht, A. (2013). Emotion Effects on the N170: A Question of Reference? *Brain Topography*, *26*(1), 62–71. https://doi.org/10.1007/s10548-012-0261-y

Rhodes, G., Locke, V., Ewing, L., & Evangelista, E. (2009). Race Coding and the Other-Race Effect in Face Recognition. *Perception*, *38*(2), 232–241. https://doi.org/10.1068/p6110

Rossignol, M., Philippot, P., Douilliez, C., Crommelinck, M., & Campanella, S. (2005). The perception of fearful and happy facial expression is modulated by anxiety: An event-related potential study. *Neuroscience Letters*, *377*(2), 115–120. https://doi.org/10.1016/j.neulet.2004.11.091

Rossion, B. (2009). Distinguishing the cause and consequence of face inversion: The perceptual field hypothesis. *Acta Psychologica*, *132*(3), 300–312. https://doi.org/10.1016/j.actpsy.2009.08.002

Rossion, B., & Jacques, C. (2011). The N170: Understanding the Time Course of Face Perception in the Human Brain. *The Oxford Handbook of ERP Components*, 115–142. https://doi.org/10.1093/oxfordhb/9780195374148.013.0064

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161–1178. https://doi.org/10.1037/h0077714

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review*, *110*(1), 145–172. https://doi.org/10.1037/0033-295X.110.1.145

Russell, J. A., & Bullock, M. (1985). Multidimensional Scaling of Emotional Facial Expressions: Similarity From Preschoolers to Adults. *Journal of Personality and Social Psychology*, *48*(5), 1290–1298.

Schacht, A., & Sommer, W. (2009). Emotions in word and face processing: Early and late cortical responses. *Brain and Cognition*, *69*(3), 538–550. https://doi.org/10.1016/j.bandc.2008.11.005

Scheller, E., Büchel, C., & Gamer, M. (2012). Diagnostic Features of Emotional Expressions Are Processed Preferentially. *PLOS ONE*, *7*(7), e41792. https://doi.org/10.1371/journal.pone.0041792

Schindler, S., & Bublatzky, F. (2020). Attention and emotion: An integrative review of emotional face processing as a function of attention. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *130*, 362–386. https://doi.org/10.1016/j.cortex.2020.06.010

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2004). The selective processing of briefly presented affective pictures: An ERP analysis. *Psychophysiology*, *41*(3), 441–449. https://doi.org/10.1111/j.1469-8986.2004.00174.x

Schupp, H. T., Ohman, A., Junghöfer, M., Weike, A. I., Stockburger, J., & Hamm, A. O. (2004). The facilitated processing of threatening faces: An ERP analysis. *Emotion (Washington, D.C.)*, *4*(2), 189–200. https://doi.org/10.1037/1528-3542.4.2.189

Schweinberger, S. R., & Neumann, M. F. (2016). Repetition effects in human ERPs to faces. *Cortex*, *80*, 141–153. https://doi.org/10.1016/j.cortex.2015.11.001

Schyns, P. G., Petro, L. S., & Smith, M. L. (2007). Dynamics of Visual Information Integration in the Brain for Categorizing Facial Expressions. *Current Biology*, *17*(18), 1580–1585. https://doi.org/10.1016/j.cub.2007.08.048

Smith, E., Weinberg, A., Moran, T., & Hajcak, G. (2013). Electrocortical responses to NIMSTIM facial expressions of emotion. *International Journal of Psychophysiology*, *88*(1), 17–25. https://doi.org/10.1016/j.ijpsycho.2012.12.004

Spielberger, C. D. (1983). *Manual for the State-Trait Anxiety Inventory*. Mind Garden.

Stefan, A. M., Gronau, Q. F., Schönbrodt, F. D., & Wagenmakers, E.-J. (2019). A tutorial on Bayes Factor Design Analysis using an informed prior. *Behavior Research Methods*, *51*(3), 1042–1058. https://doi.org/10.3758/s13428-018-01189-8

Stevens, J. S., & Hamann, S. (2012). Sex differences in brain activation to emotional stimuli: A meta-analysis of neuroimaging studies. *Neuropsychologia*, *50*(7), 1578–1593. https://doi.org/10.1016/j.neuropsychologia.2012.03.011

Sutton, T. M., Herbert, A. M., & Clark, D. Q. (2019). Valence, arousal, and dominance ratings for facial stimuli. *Quarterly Journal of Experimental Psychology (2006)*, *72*(8), 2046–2055. https://doi.org/10.1177/1747021819829012

Thompson, A. E., & Voyer, D. (2014). Sex differences in the ability to recognise non-verbal displays of emotion: A meta-analysis. *Cognition and Emotion*, *28*(7), 1164–1195. https://doi.org/10.1080/02699931.2013.875889

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Tracy, J. L., & Robins, R. W. (2007). The prototypical pride expression: Development of a nonverbal behavior coding system. *Emotion*, *7*(4), 789–801. https://doi.org/10.1037/1528-3542.7.4.789

Turano, M. T., Lao, J., Richoz, A.-R., Lissa, P. de, Degosciu, S. B. A., Viggiano, M. P., & Caldara, R. (2017). Fear boosts the early neural coding of faces. *Social Cognitive and Affective Neuroscience*, *12*(12), 1959–1971. https://doi.org/10.1093/scan/nsx110

Van Kleef, G. A. (2009). How Emotions Regulate Social Life: The Emotions as Social Information (EASI) Model. *Current Directions in Psychological Science*, *18*(3), 184–188. https://doi.org/10.1111/j.1467-8721.2009.01633.x

Van Kleef, G. A. (2010). The Emerging View of Emotion as Social Information. *Social and Personality Psychology Compass*, *4*(5), 331–343. https://doi.org/10.1111/j.1751-9004.2010.00262.x

Volpert-Esmond, H. I., Page-Gould, E., & Bartholow, B. D. (2021). Using multilevel models for the analysis of event-related potentials. *International Journal of Psychophysiology*, *162*, 145–156. https://doi.org/10.1016/j.ijpsycho.2021.02.006

Walentowska, W., & Wronka, E. (2012). Trait anxiety and involuntary processing of facial emotions. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *85*(1), 27–36. https://doi.org/10.1016/j.ijpsycho.2011.12.004

Whalen, P. J., Shin, L. M., McInerney, S. C., Fischer, H., Wright, C. I., & Rauch, S. L. (2001). A functional MRI study of human amygdala responses to facial expressions of fear versus anger. *Emotion*, *1*(1), 70–83. https://doi.org/10.1037/1528-3542.1.1.70

Willenbockel, V., Sadr, J., Fiset, D., Horne, G. O., Gosselin, F., & Tanaka, J. W. (2010). Controlling low-level image properties: The SHINE toolbox. *Behavior Research Methods*, *42*(3), 671–684. https://doi.org/10.3758/BRM.42.3.671

Wronka, E., & Walentowska, W. (2011). Attention modulates emotional expression processing. *Psychophysiology*, *48*(8), 1047–1056. https://doi.org/10.1111/j.1469-8986.2011.01180.x

Zhao, K., Zhao, J., Zhang, M., Cui, Q., & Fu, X. (2017). Neural Responses to Rapid Facial Expressions of Fear and Surprise. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00761

Appendix A
Circumplex Figure

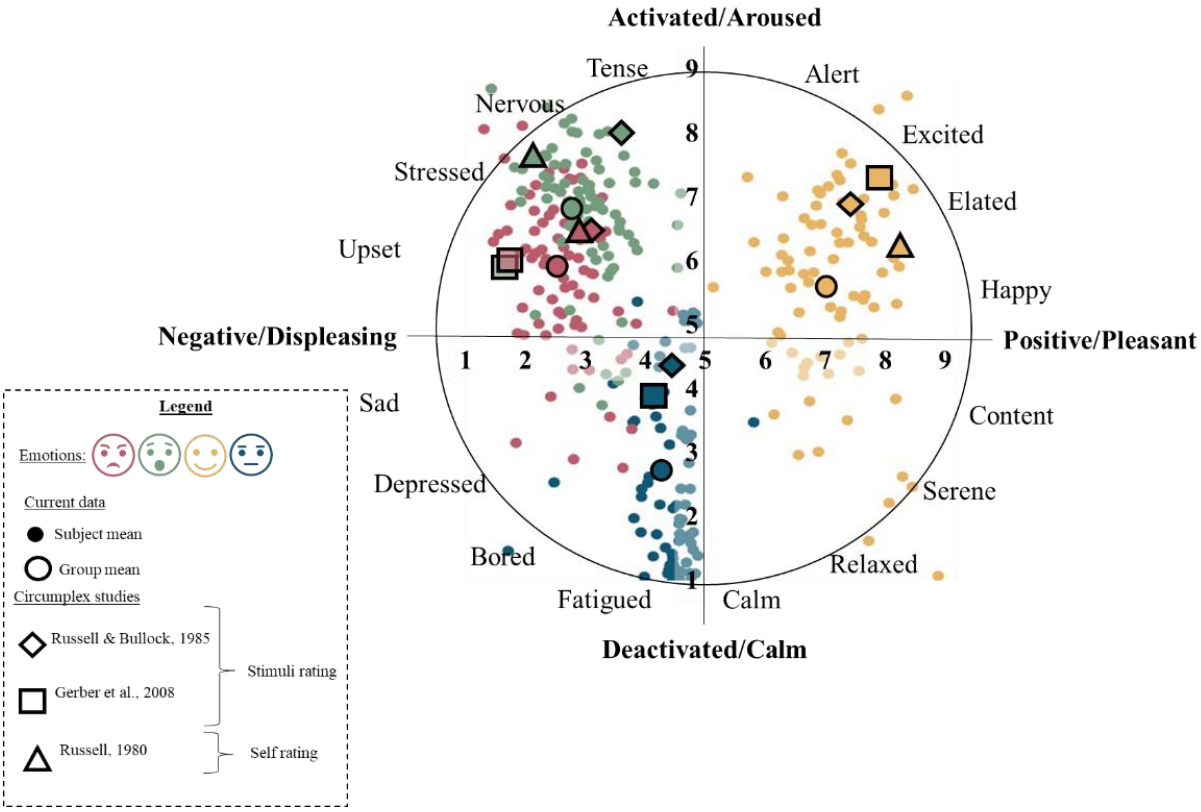


Figure 1. Graphical depiction of traditional circumplex model (developed by Russell, 1980) overlayed with the present data (subject means in solid dots, sample means in dots with borders). Approximate mean data collected in circumplex validation studies rating facial expressions (i.e., stimuli rating; diamonds - Russell & Bullock, 1985; squares - Gerber et al., 2008) and participant experiences (i.e., self-rating; triangles - Russell, 1980) are also superimposed. Symbols are colour coded based on emotional expression, where anger is pink, fear is green, happiness is yellow, and neutral is blue. Subject means that are lighter in colour are underneath of the axis, which a white background underlies to ensure legibility.

Appendix B
Detailed Result Tables

N-H	Time	Electrodes	Maximal	Components
Original	262-314ms	Pz, P3, P5, P7, PO7, PO3, POz, Oz, O1, CP2, P2, P4, P6, P8, P10, PO10, PO8, PO4	298ms on PO4 (F = 16.65, p = .001, $\Delta\mu V$ = 0.62).	EPN
	268-302ms	Fp1, AF7, F3, F5, F7, FC5, FC3, FC1, Fpz, AFz, Fz, F4, FCz	286ms on AFz (F = 10.51, p = .001, $\Delta\mu V$ = -0.66).	
	328-348ms	PO3, POz, Oz, O1	348ms at POz (F = 12.29, p = .001, $\Delta\mu V$ = 0.53).	EPN
Arousal	272-314ms	POz, PO3, Oz, O1, CP2, P2, P4, P6, PO8, PO4	290ms on POz (F = 9.87, p = .001, $\Delta\mu V$ = 0.53).	EPN
	282-294ms	FP1, AF7, AFz	284ms on Fp1 (F = 6.42, p = .002, $\Delta\mu V$ = -0.44).	
Valence	180-200ms	P8, P10, PO10	PO10 198ms (F = 9.50, p = .001, $\Delta\mu V$ = 0.24)	P2
	260-318ms	PO7, PO3, POz, Oz, O1, CP2, P2, P4, P6, P8, P10, PO10, PO8, PO4	296ms at PO4 (F = 13.23, p = .001, $\Delta\mu V$ = 0.61).	EPN
	274-298ms	F3, F5, FC3, FC1, AFz, Fz, FC2, FCz	288ms on FCz (F = 7.18, p = .001, $\Delta\mu V$ = -0.40).	

Table 1. Breakdown of significant clusters from the **neutral vs. happy expression contrast**. The table contains the test type (original, arousal, or valence), the time of the cluster, what electrodes were included, where and when the cluster had the largest *F*-value, and lastly what ERP components were included in the cluster.

N-A	Time	Electrodes	Maximal	Components
Original	116-130ms	P4, P6, P8, P10, PO10, PO8, PO4,	126ms on PO10 (F = 15.88, p = .001, $\Delta\mu V$ = -0.60).	P1
	120-130ms	FC3, C1, C3	124ms on FC3 (F = 9.08, p = .005, $\Delta\mu V$ = 0.30).	P1
	148-238ms	FC1, C1, TP9, TP7, CP1, CPz, Pz, P1, P7, P9, PO9, PO7, Oz, O1, Iz, Fz, FC4, FC2, FCz, Cz, C2, TP10, CP4, CP2, P4, P6, P8, P10, PO10, PO4, O2	164ms on P9 (F = 22.41, p = .001 , $\Delta\mu V$ = 0.69)	N170-P2
	216-228ms	AF7, F3, F5, F7, FC5,	222ms on AF7 (F = 8.84, p = .003 , $\Delta\mu V$ = -0.48).	
	294-304ms,	AF7, F5, F7	304ms on AF7 (F = 8.22, p = .005, $\Delta\mu V$ = -0.50).	
	312-340ms	AF7, F5, F7	322ms on F7 (F = 11.01, p = .001, $\Delta\mu V$ = -0.63).	
Arousal	154-162ms	TP9, P9, PO9	160ms on P9 (F = 9.69, p = .004 , $\Delta\mu V$ = 0.67)	N170-P2
	154-172ms	CPz, Pz, P1	162ms on Pz (F = 10.23, p = .001 , $\Delta\mu V$ = -0.53)	N170-P2
Valence	118ms-128ms	P6, P10, PO10, PO8, PO4	124ms on PO10 (F = 9.33, p = .001, $\Delta\mu V$ = -0.60)	
	122-130ms	FC3, C1, C3	124ms on C1, F = 7.1534, p = .003, $\Delta\mu V$ = 0.3565	
	154-168ms	CPz, Pz, P1, Cz, CP2,	160ms on Pz (F = 9.55, p = .001, $\Delta\mu V$ = -0.53).	VPP
	150-172ms	TP9, TP7, P7, P9, PO9	162ms on P9 (F = 13.45, p = .001 , $\Delta\mu V$ = 0.68)	

Table 2. Breakdown of significant clusters from the **neutral vs. angry expression contrast**. The table contains the test type (original, arousal, or valence), the time of the cluster, what electrodes were included, where and when the cluster had the largest *F*-value, and lastly what ERP components were included in the cluster.

N-F	Time	Electrodes	Maximal	Components
Original	116-129ms	CPz, Pz, P1, P2	128ms on CPz (F = 6.18, p = .005 , $\Delta\mu V$ = -0.38])	N170 downslope
	120-182ms	FC1, C1, TP9, TP7, CPz, Pz, P7, P9, PO9, PO7, Oz, O1, Iz, Afz, Fz, FC4, FC2, FCz, Cz, C2, TP10, CP4, P6, P8, P10, PO10	148ms on P10 (F = 25.08, p = .001 , $\Delta\mu V$ = 0.80)	N170
Arousal	N/A			
Valence	126-166ms	TP9, TP7, P7, P9, PO7, PO9, PO7, Oz, O1, IzTP10, CP6, P6, P8, P10, PO10,	150ms on P8 (F = 21.89, p = .001 , $\Delta\mu V$ = 0.82)	N170

Table 3. Breakdown of significant clusters from the **neutral vs. fearful expression contrast**. The table contains the test type (original, arousal, or valence), the time of the cluster, what electrodes were included, where and when the cluster had the largest *F*-value, and lastly what ERP components were included in the cluster.

H-A	Time	Electrodes	Maximal	Components
Original	110-140ms	PO3, POz, Oz, O1, Iz, P4, P6, P8, P10, PO10, PO8, PO4	116ms on Oz (F = 17.33, p = .001 , $\Delta\mu V$ = -0.54)	N170 downslope
	120-134ms	FP1, AF7, FC3, FC1, C1, FPz, Afz, Fz, F4, FC4, FC2, FCz,	130ms on AFz (F = 9.42, p = .001, $\Delta\mu V$ = 0.48).	
	158-180ms	CP1, CPz, Pz, P1, POz, Cz, CP2, P2, O2	178ms on CP2 (F = 12.66, p = .001, $\Delta\mu V$ = -0.36)	VPP
	178-192ms	TP9, P9, PO9,	182ms on P9 (F = 8.61, p = .001, $\Delta\mu V$ = 0.63)	P2
	186-204ms	TP10, P8, P10	188ms on P8 (F = 12.64, p = .001, $\Delta\mu V$ = 0.64)	P2
	212-216ms	TP10, P8, P10	212ms on P8 (F = 10.56, p = .008, $\Delta\mu V$ = 0.66)	P2
	270-276ms	PO3, POz, O1	270ms on POz. (F = 10.56, p = .008, $\Delta\mu V$ = -0.37)	EPN
Arousal	112-138ms	PO7, PO3, POz, Oz, O1, Iz, P6, P8, P10, PO10, PO8, PO4	124ms on PO4 (F = 12.12, p = .001, $\Delta\mu V$ = -0.48).	N170 downslope
	122-130ms	Afz, F4, FC4, FC2, FC3, FC1, C1	130ms on AFz (F = 6.96, p = .001, $\Delta\mu V$ = 0.48)	
	164-174ms	CPz, Pz, P1, Cz, CP2	164ms on Cz (F = 6.11, p = .001, $\Delta\mu V$ = -0.28)	VPP
Valence	N/A			

Table 4. Breakdown of significant clusters from the **happy vs. angry expression contrast**. Table contains the test type (original, arousal, or valence), the time of the cluster, what electrodes were included, where and when the cluster had the largest *F*-value, and lastly what ERP components were included in the cluster.

H-F	Time	Electrodes	Maximal	Components
Original	120-163ms	CP1, CPz, Pz, P1, POz, Cz, CP2, P2	132ms on CP2 (F = 7.65, p = .001, $\Delta\mu V$ = -0.42)	P1-N170
	264-292ms	POz, Cp2, P2, P4, P6, PO8, PO4	278ms on PO4 (F = 9.38, p = .001, $\Delta\mu V$ = -0.39)	EPN
	272-292ms	F3, FC3, FC1, Fz, FCz,	282ms on F3 (F = 12.87, p = .001, $\Delta\mu V$ = 0.48)	EPN
Arousal	262-298ms	POz, P2, P4, P6, PO8, PO4	282ms on PO4 (F = 10.39, p = .001, $\Delta\mu V$ = -0.38)	EPN
	272-294ms	F3, F5, FC3, FC1, Fz, FC2, FCz,	284ms on F3 (F = 13.14, p = .001, $\Delta\mu V$ = 0.48).	EPN
Valence	276-296ms	P4, P6, PO4	276ms on PO4 (F = 10.97, p = .001, $\Delta\mu V$ = -0.39)	EPN

Table 5. Breakdown of significant clusters from the **happy vs. fearful expression contrast**. Table contains the test type (original, arousal, or valence), the time of the cluster, what electrodes were included, where and when the cluster had the largest *F*-value, and lastly what ERP components were included in the cluster.

A-F	Time	Electrodes	Maximal	Components
Original	108-140ms	FC3, FC1, C1, C3, TP9, TP7, CP1, CPz, Pz, P1, P7, P9, PO9, PO7, Oz, O1, Iz, FC4, FC2, FCz, Cz, C2, CP6, CP4, P6, P8, P10, PO10, PO4, O2	130ms on P10 (F = 26.30, p = .001, $\Delta\mu V$ = 0.83).	P1
	168-184ms	Pz, P1, PO3, POz,	180ms on Poz (F = 9.40, p = .001, $\Delta\mu V$ = 0.39)	P2
Arousal	106-138ms	FC3, FC1, C1, C3, TP9, TP7, CP1, CPz, Pz, P1, P7, P9, PO9, PO7, Oz, O1, Iz, FC4, FC2, FCz, Cz, C2, CP6, CP4, P6, P8, P10, PO10, PO4, O2	130ms on P10 (F = 23.92, p = .001, $\Delta\mu V$ = 0.83)	P1
	172-182ms	Pz, P1, PO3, POz,	180ms on POz (F = 8.09, p = .005, $\Delta\mu V$ = 0.39)	P2
	210-220ms	TP10, P8, PO10	210ms on TP10 (F = 6.08, p = .007, $\Delta\mu V$ = -0.31)	N/A
Valence	112-140ms	FC3, FC1, C1, C3, TP9, TP7, CP1, CPz, P1. P7, P9, PO9, PO7, Oz, O1, Iz, FC4, FC2, FCz, Cz, C2, CP4, P6, P8, P10, PO10, PO4, O2	130ms on P10 (F = 23.84, p = .001, $\Delta\mu V$ = 0.83)	P1
	168-182ms	Pz, P1, PO3, POz	178ms on POz (F = 9.98, p = .001, $\Delta\mu V$ = 0.39)	P2

Table 6. Breakdown of significant clusters from the **angry vs. fearful expression contrast**. Table contains the test type (original, arousal, or valence), the time of the cluster, what electrodes were included, where and when the cluster had the largest *F*-value, and lastly what ERP components were included in the cluster.

Appendix C
Exploratory Regression Results

Exploratory correlation analyses investigated how participants mean valence or arousal ratings for each emotion related to the corresponding ERP modulation. This analysis deviates from the original analysis, which uses stimuli-level ratings on a trial-by-trial basis. Whereas the present analysis highlights the role of systematic individual differences pooled across all faces in a certain expression category.

These analyses were computed in LIMO EEG at the second level, using data from the original analysis at the first level. Correlations were computed with $\alpha = .05$ and cluster mass corrections for multiple comparisons. Only the significant results are shown in Appendix C Fig.1 below.

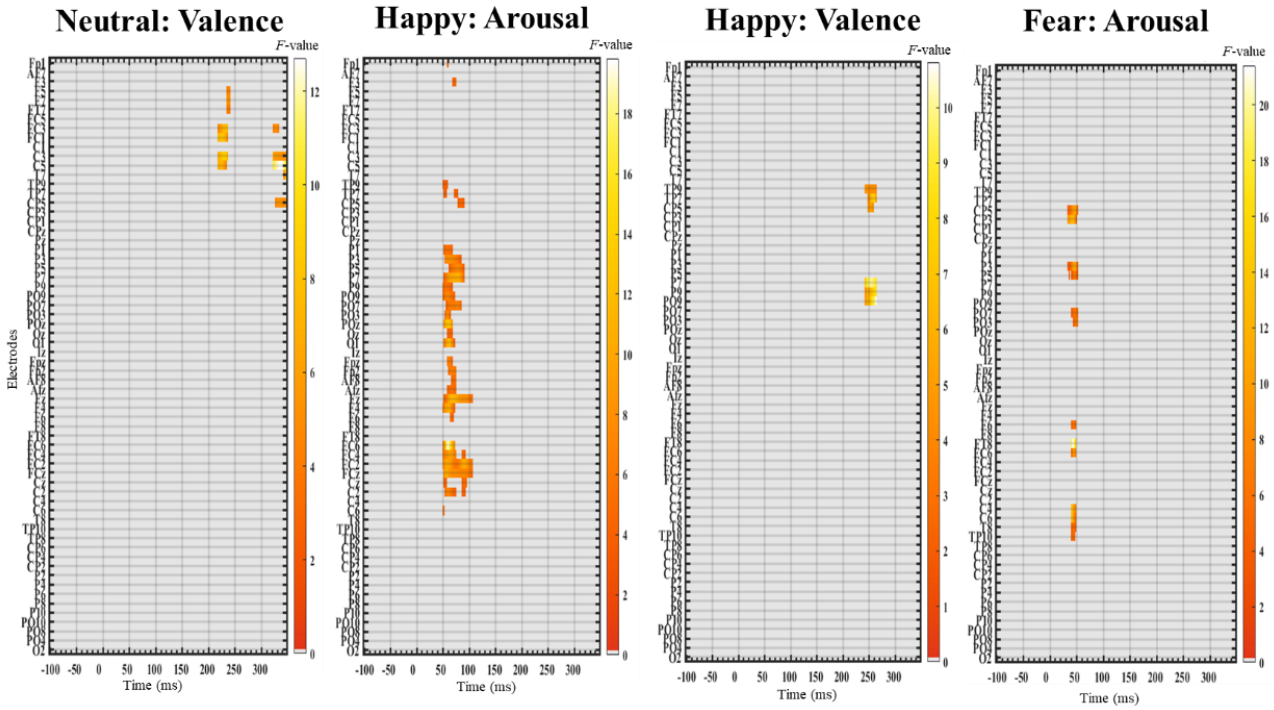


Figure 1. Correlation analyses results. Time (ms) is plotted along the x-axis, with 0ms representing the onset of the face stimuli. Electrodes are plotted along the y-axis. Significant data points are coloured with respect to their *F*-Value (use colour bar on right of each plot for reference).

Neutral expressions

Amplitudes in response to neutral expressions did not correlate with arousal ratings when using the cluster-mass correction.

Valence ratings, in contrast, correlated with ERPs to neutral faces. Two significant clusters emerged over left fronto-central electrodes. Both clusters indicated a positive correlation, whereby the more positive participants viewed the face, the more positive their amplitudes were during these clusters. Specifically, the first cluster spanned 218-240ms and was largest on C3 at 228ms ($F = 8.83$, $R^2 = 0.10$, $p = 0.041$). The second cluster was from 322-348ms and was largest on C5 at 336ms ($F = 12.70$, $R^2 = 0.14$, $p = 0.03$).

Happy expressions

Amplitudes in response to happy faces correlated with arousal ratings. Two significant clusters emerged. The first was a positive correlation, from 50-90ms on left temporal, parietal, and occipital sites, maximum at 60ms POz ($F = 13.38$, $R^2 = 0.15$, $p = 0.001$). The second cluster was a negative correlation, from 50-109ms on right fronto-central electrodes, maximum on FC6 at 60ms ($F = 19.84$, $R^2 = 0.20$, $p = 0.001$).

Happy amplitudes also correlated with valence ratings. One significant cluster was seen, from 242-264ms on a few left temporal and parietal electrodes. This effect was maximal at 264ms on PO9 ($F = 10.82$, $R^2 = 0.12$, $p = 0.016$). This cluster indexed a negative correlation, where the more positive the valence ratings, the more negative the amplitudes.

Angry expressions

Angry expressions did not correlate with valence or arousal ratings when corrected for multiple comparisons.

Fearful expressions

Fearful expressions did correlate with arousal ratings. Two clusters were seen. The first was a negative correlation from 34-52ms on left central and parietal electrodes, maximal on CP3 at 42ms ($F = 13.08$, $R^2 = 0.15$, $p = 0.025$). The second cluster had a positive correlation from 40-48ms on right frontal, central, and temporal sites, peaking at 44ms on FT8 ($F = 21.41$, $R^2 = 0.22$, $p = 0.044$). Fearful expressions did not correlate with valence ratings when corrected for multiple comparisons.