

# Overt and covert attention shifts to emotional faces: Combining EEG, eye tracking, and a go/no-go paradigm

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## Abstract

In everyday life, faces with emotional expressions quickly attract attention and eye movements. To study the neural mechanisms of such emotion-driven attention by means of event-related brain potentials (ERPs), tasks that employ covert shifts of attention are commonly used, in which participants need to inhibit natural eye movements towards stimuli. It remains, however, unclear how shifts of attention to emotional faces with and without eye movements differ from each other. The current preregistered study aimed to investigate neural differences between *covert* and *overt* emotion-driven attention. We combined eye tracking with measurements of ERPs to compare shifts of attention to faces with happy, angry, or neutral expressions when eye movements were either executed (go conditions) or withheld (no-go conditions). Happy and angry faces led to larger EPN amplitudes, shorter latencies of the P1 component, and faster saccades, suggesting that emotional expressions significantly affected shifts of attention. Several ERPs (N170, EPN, LPC) were augmented in amplitude when attention was shifted with an eye movement, indicating an enhanced neural processing of faces if eye movements had to be executed together with a reallocation of attention. However, the modulation of ERPs by facial expressions did not differ between the go and no-go conditions, suggesting that emotional content enhances both covert and overt shifts of attention. In summary, our results indicate that overt and covert attention shifts differ but are comparably affected by emotional content.

## KEYWORDS

early posterior negativity, emotion-driven attention, ERPs, eye movements, overt attention

## 1 | INTRODUCTION

Emotional faces quickly attract our attention (Junghöfer et al., 2006; Pourtois et al., 2004) and gaze (Hunt et al., 2007), even when presented below the threshold of awareness (Vetter et al., 2019). However, some social situations warrant

that direct eye movements towards other people (i.e., overt shifts of attention) are inhibited avoiding awkward situations when incidentally looking at strangers (Foulsham et al., 2011; Hayward et al., 2017; Laidlaw et al., 2011). Behavioral studies have shown that people prefer to look at faces over other stimuli on a computer screen but avoid

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looking at them in everyday settings (Foulsham et al., 2011; Hayward et al., 2017; Laidlaw et al., 2011). Even if no eye movements take place, attention may still be shifted towards other people's faces without looking at them (covert attention shift). Consequently, to get a clear picture of attention in real life situations, both overt and covert attention shifts need to be considered. However, the neural mechanisms of overt and covert attention shifts to emotional faces, where attentional shifts are accompanied by an overt shift of gaze or not, have never been directly compared in a paradigm that manipulates both types of attention shift. Such a comparison is however crucial, to relate findings from the new stream of real-life studies involving both overt and covert attention (Argyle & Cook, 1976; Gobel et al., 2015; Nasiopoulos et al., 2015; Risko et al., 2016) to laboratory-based electroencephalography (EEG) tasks that often require only covert attention. The central aim of this study is to undertake this comparison and directly test the neural mechanisms of overt and covert shifts of attention to emotional stimuli against each other.

There is ample evidence that emotional content increases the overall perceptual salience of faces. For instance, it has been shown that enhanced salience of emotional (e.g., fearful) faces results in a facilitation of their detection compared to neutral faces (Bayle et al., 2011) and leads to a higher propensity of eye movements towards them (Bannerman et al., 2012; Kissler & Keil, 2008; Nummenmaa et al., 2006). However, when fast, reflexive first saccades to face stimuli were investigated, no effect of expression was found (Kulke, 2019). Together, these studies suggest that emotional salience and physical salience may have similar behavioral and neural correlates. Whereas the neural correlates of covert and overt shifts of attention to emotionally salient stimuli have not been tested before, previous research has examined the underlying neural mechanisms of the two types of attention shifts. For instance, Kulke et al., (2016a) combined eye tracking and EEG with a fixation shift paradigm (Atkinson et al., 1988, 1992; Hood & Atkinson, 1993; Kulke et al., 2015) and asked participants to either make an overt attention shift (i.e., involving an eye movement) towards a peripheral target or to make a covert attention shift (i.e., keep fixating their gaze on the center). The study used high contrast bars as target stimuli, demonstrating that mechanisms for covert and overt attention shift to such physically salient targets are similar in occipital areas (Kulke et al., 2016a) but subtly differ in frontal responses, possibly due to the inhibition of eye movements (Bokura et al., 2001; Kulke et al., 2016a). However, it is unknown whether these findings also extend to situations where socio-emotional relevance rather than physical salience is enhanced.

Neural responses to faces differ from those to simple physically salient targets. Faces are selectively processed in the fusiform face area (Kanwisher et al., 1997), where neurons are more responsive to faces than other objects, among

others, and lead to enhanced neural responses, in particular of the N170 (Bentin et al., 1996; Eimer, 2000; Itier & Taylor, 2004). Previous studies reported larger event-related brain potential (ERP) responses towards emotional compared to neutral faces at different levels of processing, including the P1, N170, early posterior negativity (EPN), and late positive component (LPC) (Batty & Taylor, 2003; Hinojosa et al., 2010, 2015; Rellecke et al., 2012; Schacht & Sommer, 2009; Schupp et al., 2004), although the earliest time when emotion effects start to emerge remains unclear (for a recent review, see Schindler & Bublatzky, 2020). While some authors found very early neural differences between neutral and emotional faces on the C1 (Pourtois et al., 2004), P1 (Hammerschmidt et al., 2017; Pourtois et al., 2005; Rellecke et al., 2011; Vlamings et al., 2009), or N170 (for reviews, see Hinojosa et al., 2015; Rellecke et al., 2013), other studies failed to find such early emotion effects on the P1 (Frühholz et al., 2011; Rossignol et al., 2012) or N170 (Eimer & Holmes, 2002). The onset of emotion effects on ERPs therefore remains unclear and has mainly been studied in lab-based tasks, where participants are instructed to inhibit eye movements (for a recent review, see Schindler & Bublatzky, 2020).

An important reason that electrophysiological underpinnings of overt emotion-driven attention are not well characterized is that eye movements typically lead to artifacts in EEG data (Anllo-Vento & Hillyard, 1996; Eimer et al., 2002, 2005; Hopfinger & Mangun, 1998; Martinez et al., 1999; Praamstra & Oostenveld, 2003; Shomstein et al., 2012; Yamaguchi et al., 1994, 1995). To accommodate for this, most previous studies have resorted to measuring covert shifts of attention. More recently, it became possible to investigate overt attention shifts by combining EEG and eye tracking (Dimigen et al., 2011; Huber-Huber et al., 2016; Kulke, 2015, 2019; Kulke et al., 2016a, 2016b, 2020; Weaver et al., 2017). Specifically, two studies (Kulke et al., 2016a, 2020) combined eye tracking and EEG to investigate the neural mechanisms of covert and overt attention shifts to physical salience. These previous studies thus suggest that eye tracking and EEG recording can be successfully combined to investigate neural correlates of overt attentional shifts, despite eye movement-related artifacts in EEG data.

While previous ERP research mainly focused on covert attention, fMRI studies have undertaken a comparison of covert and overt attention to neutral stimuli (Phillips et al., 2004) and found either overlapping (Beauchamp et al., 2001; De Haan et al., 2008; Nobre et al., 2000) or distinct neural correlates for the two types of attention (Fairhall et al., 2009). Another related line of fMRI research compared overt and covert presentation of emotional faces that could elicit different degrees of awareness of emotional content (Phillips et al., 2004; Sabatini et al., 2009). However, these previous studies did not test emotion-driven attention shifts. Across various neuroimaging techniques, only one study investigated

ERPs related to reflexive overt attention shifts to emotional faces (Kulke, 2019). The findings suggest that during overt attention shifts emotional expressions of the target faces impact only those ERPs that occur after the eye movements have been completed (EPN) but not early responses (P1) before the saccades. To our knowledge, attention shifts with and without eye movements to emotional faces have never been directly compared. It therefore remains unclear, whether brain mechanisms of attention shifts to emotional faces differ depending on whether eye movements occur or not and whether those differences are modulated by emotional content that the faces convey. If eye movements play a crucial role when humans gather emotional information about others, emotion effects should be significantly enhanced when they are accompanied by an eye movement (i.e., during overt attention shifts). If, however, emotion can just as reliably be processed during covert attention shifts, no differences in emotion effects should occur when the eyes are moved towards the emotional object, suggesting that no direct gaze is required to evaluate other people's emotional state during social interactions.

## 1.1 | Aims and hypotheses

The present pre-registered (<https://osf.io/4kscq>) study aimed to investigate neural differences in shifts of attention with and without eye movements, depending on whether the target is a neutral compared to an emotional (happy, angry) face. A go/no-go task was used, in which participants were explicitly instructed to make an eye movement towards peripheral faces (go) or not (no-go condition). These explicit instruction conditions were used to manipulate overt and covert attention in a controlled fashion, although it should be noted that both types of attention shifts are freely selected during natural gaze. It has been suggested that attention is shifted covertly towards briefly presented targets even if eye movements need to be suppressed (Belopolsky & Theeuwes, 2012; Mulckhuyse et al., 2007; Van der Stigchel & Theeuwes, 2007). In our coregistration set-up, eye tracking was used to measure whether and how quickly attention is shifted overtly, while simultaneous EEG was used to measure underlying neural mechanisms. We expected neural responses to be affected by the emotional expression of the target and by the overtness of an attention shift. Specifically, based on previous behavioral findings (Bannerman et al., 2012; Bayle et al., 2011; Kissler & Keil, 2008; Nummenmaa et al., 2006), we predicted that the attentional draw of emotional stimuli makes it difficult to inhibit eye movements towards them. Therefore, we expected shorter saccade and P1 latencies in response to emotional compared to neutral faces and more errors (i.e., erratic saccades in no-go trials with emotional compared to neutral facial expressions). As frontal regions have been found to respond to saccade inhibition effort (Bokura

et al., 2001; Kulke et al., 2016a), we expected larger frontal responses in no-go compared to go conditions, varying with emotional expression. We further expected enhanced amplitudes of later ERP components (N170, EPN, and LPC) in response to emotional than to neutral faces, independent of saccade execution. As emotional processing differs between individuals (Hamann & Canli, 2004; Kaltwasser et al., 2014; Recio et al., 2017), particularly depending on social anxiety (Bradley et al., 2000; Mogg et al., 2004; Wieser et al., 2009, 2018), participants were preselected for this study to test a wide distribution of nonclinical differences in social anxiety and findings regarding individual differences are reported in Supporting Information A.

In summary, the current study aimed to investigate the effects of (a) emotion and (b) eye movements on neural mechanisms of attention. It sought to disentangle the mechanisms involved in covert attention shifting paradigms, as used in the previous literature and overt shifts, which occur in everyday life, thereby expanding our knowledge of the neural mechanisms that underlie processing of social information in naturalistic environments.

## 2 | METHOD

### 2.1 | Participants

The study was preregistered with the Open Science Framework (<https://osf.io/4kscq>). To preselect participants based on social anxiety traits, a prescreening was programmed with SoSci survey (<https://soscisurvey.de/>, Leiner, 2019). One hundred healthy participants between 18 and 35 years completed the Social Interaction Anxiety Scale (SIAS) questionnaire (Stangier et al., 1999) online. This 20-item questionnaire with a 5-point response scale was first developed and validated by Mattick and Clarke (1998) and evaluated and translated into German by Stangier et al. (1999). The questionnaire assesses a general fear of social interactions, with higher scores indicating higher levels of social anxiety. Based on diagnostic criteria for social phobia from the diagnostic manual of mental disorders (DSM; American Psychiatric Association [APA], 2013), SIAS is widely used in research and clinical practice. Internal consistency was high for the current study ( $\alpha = 0.92$ ). In return for participation in the prescreening, participants took part in a raffle for two Amazon vouchers (10€).

Based on the resulting distribution of SIAS scores, four quantiles were formed, with four equally sized sections based on the respective median ( $Mdn = 18$ ,  $min = 2$ ,  $max = 50$ ,  $Q0.25 = 11.75$ ,  $Q0.5 = 18$ ,  $Q0.75 = 29.25$ ). Ten subjects were randomly selected from each quantile and invited via e-mail to participate in the subsequent EEG experiment in order to ensure a sufficient variance of SIAS scores in the EEG data

( $M = 20.175$ ,  $SD = 11.703$ ,  $min = 3$ ,  $max = 49$ ). The sample size was based on previous studies (Hammerschmidt et al., 2018; Kulke, 2019; Kulke et al., 2016a). Eleven subjects did not reply and were replaced by other participants randomly selected from the respective quantiles. Three additional participants needed to be excluded and replaced due to excessive noise (over 50% lost trials) in the eye-tracking ( $n = 1$ ) or ERP data ( $n = 2$ ). The final sample contained 14 male and 26 female participants (age range 19–29 years,  $M = 23.2$ ,  $SD = 2.7$ ). No participant needed to be excluded due to a score above the clinical cut-off value (32+) of the Autism Quotient Questionnaire (Baron-Cohen et al., 2001). The study was approved by the local ethics committee and in line with the Declaration of Helsinki. All participants gave written informed consent prior to participation in the study.

## 2.2 | Stimuli and materials

### 2.2.1 | Face stimuli

The stimuli comprised 30 colorful faces from ten different individuals (five male and five female), selected from the Karolinska Directed Emotional Faces database (Lundqvist et al., 1998), which has been validated, showing that participants correctly identify the displayed emotions (Goeleven et al., 2008), each displaying angry, neutral, and happy facial expressions. Images were ellipsoid with a size of  $4.5 \times 7$  cm (corresponding to a visual angle of  $3.4^\circ \times 5^\circ$  for the viewing distance of 80 cm) and consisted of  $324 \times 504$  pixels. Stimuli were identical to the ones used by (Kulke, 2019) and trimmed to exclude external features such as hair, ears, and clothing and controlled for luminance, if required (Hammerschmidt et al., 2017). All images were displayed on a white background on a liquid crystal display (LCD) computer screen with a 60-Hz refresh rate.

## 2.3 | Procedure

Prior to the start of the experiment, participants provided a written informed consent. After the EEG electrodes were applied and the eye tracker was calibrated and validated (see details below), the experimental session began and subjects were instructed on the go/no-go task. The trial sequence was programmed with Python and PsychoPy, based on previous research (Kulke, 2019), with additional no-go trials. The frequencies of go and no-go trials were equal (0.50/0.50), as in previous similar studies using a go/no-go paradigm (Jodo & Kayama, 1992; Kulke et al., 2016a; Recio et al., 2009). At the start of each trial, a fixation cross with a size of 0.7 cm (50 pixels,  $0.5^\circ$ ) was presented at the center of the screen for a randomized interval of 1,500–2,500 ms. If participants

fixated within an area of 40 pixels ( $0.56$  cm,  $0.4^\circ$ ) around the fixation cross for at least 150 samples (corresponding to 333.33 ms at a sampling rate of 500 Hz) at the end or following this interval, the fixation cross gaze-contingently changed its color from black to either blue or orange, indicating a go or no-go condition (color assignment counterbalanced across participants). Simultaneously, with the color change of the fixation cross, a face stimulus was presented 5.6 cm (400 pixels,  $4^\circ$ ) to the right or the left side.<sup>1</sup> Participants were instructed to move their eyes towards peripheral face stimuli in go trials and withhold an eye movement in no-go trials. In go trials, the face disappeared when participants fixated within 40 pixels ( $0.56$  cm,  $0.4^\circ$ ) of the image for at least 150 samples (= 333.33 ms). In no-go trials, the face disappeared after 700 ms, and the next trial started.

The experiment consisted of twelve blocks with 100 trials each, with short breaks in-between, and lasted approximately one hour. Each expression was randomly presented 100 times per side and per condition. The order of all trials was randomized.

At the end of the EEG experiment, participants completed the “Reading Mind in the Eye” test (Baron-Cohen et al., 2001), the German version of the Behavioral Inhibition/Behavioral Avoidance Scale (BIS/BAS; Strobel et al., 2001), the Barratt–Impulsiveness Scale short version (BIS-15; Meule et al., 2011), and the Autism Quotient Questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, et al., 2001). Participants received course credit or monetary reward (17€) in return for participation.

## 2.4 | Eye-tracking data processing

Eye movements from both eyes were recorded continuously throughout the experiment with a desktop-mounted eye tracker (Eyelink 1,000, SR Research, Ontario, Canada) at a sampling rate of 500 Hz. A chinrest was used to minimize head movements and to ensure an average viewing distance of 80 cm. Prior to the start of the experiment, each participant completed a standardized 9-point calibration and validation procedure. At the beginning of each presentation block, an additional 1-point calibration was completed to ensure a constantly high data quality. After

<sup>1</sup>In order to ensure that emotions can be perceived at this eccentricity, a pilot study was conducted in which participants who were blind to the aim and had not previously seen the images correctly identified 95% of expressions at this eccentricity when it was controlled with eye tracking that they kept fixating centrally. This suggests that emotions were successfully identified at this eccentricity, with comparable recognition rates as in the KDEF validation by Goeleven et al. (2008; hit rate ranging from 62.64% for neutral up to 92.65% for happy faces). Previous research furthermore demonstrated clear neural effects of emotional expression when faces were presented at such an eccentricity (Kulke, 2019).

completion of the experiment, the raw eye-tracking data were preprocessed in Matlab version R2017a based on previous research (Kulke, 2019). Gaze position data were averaged across both eyes. Horizontal saccades were determined as a gaze change in x-position of more than  $0.4^\circ$  between two subsequent samples (see e.g., Kulke, 2015, 2019; Kulke et al., 2016a). The latency of the first saccade after target onset was computed in go trials. Saccades occurring faster than 100 ms after stimulus onset were rejected as they are unlikely to be target related, and saccades slower than 700 ms were rejected as too slow. Furthermore, trials were excluded from further analysis if the fixation at the beginning of each trial was not within an area of  $0.4^\circ$  around the fixation cross; if too many changes in fixation position were visible, indicative of noisy data or if eye movements were incorrect ( $M = 8.5\%$  of trials excluded). Errors (i.e., accidental eye movements) were determined in no-go trials.

## 2.5 | EEG data processing

EEG was recorded at a sampling rate of 512 Hz from 64 active Ag-AgCl electrodes mounted in an elastic electrode cap (Easy-Cap, BioSemi, Amsterdam, the Netherlands) in line with the extended 10–20 international system (Pivik et al., 1993). Additionally, six external electrodes were placed below the eyes (2), on the outer edges of the eyes (2), and to the left and right mastoids (2). Recordings were made with the common mode sense (CMS) electrode and the driven right leg (DRL) passive electrode as reference and ground electrodes. EEG was recorded using the ActiView707 BioSemi recording software for Linux. Electrode offsets were kept below  $\pm 25$  mV.

Offline processing was conducted in Matlab version R2017a and the EEGLab toolbox (Delorme & Makeig, 2004), based on previous research (Kulke, 2019; Kulke et al., 2016a). Trials with erroneous responses (errors of commission and omission) were excluded. External channels were removed, and continuous data were baseline corrected using a 200-ms time interval prior to face stimulus onset. Filtering processes were done with a second-order Butterworth bandpass filter with a high-pass boundary of 0.01 Hz and a low-pass boundary of 25 Hz. Very low high-pass filters were used to avoid filter distortions in data with task-relevant eye movements (Kulke & Kulke, 2020). To remove 50-Hz line noise, the CleanLine plugin (Mullen, 2012) was used; note that this was applied after the low-pass filter of 25 Hz was applied because some residual line noise may remain even after the low-pass filter was applied. The EEG data was re-referenced offline to the average reference and down-sampled from 512 to 500 Hz after baseline correction. The system delay

between the trigger signal and the visual presentation on the computer monitor was determined to be 24 ms, using a light-sensitive diode, and the triggers were shifted accordingly. Trials with noisy eye-tracking data were excluded from further EEG analysis.

An independent component analysis (ICA) was conducted on a separate dataset, on which stronger high-pass filters of 1 Hz and a low-pass boundary of 40 Hz were applied. After extracting epochs of  $-200$  to  $1,000$  ms around stimulus onset, the ICA was conducted using the EEGLAB plug-in ADJUST (Mognon et al., 2011). Two trained coders independently marked independent components (ICs) that were unambiguously eye components (vertical eye movements, horizontal eye movements, and blinks). ICs unanimously identified by both coders were rejected from the final data set ( $M = 4.375$  per participant,  $SD = 1.372$ ,  $min = 2$ ,  $max = 9$ ).

The ICA weights from the separate ICA dataset were then applied to the original dataset. EEG data was epoched based on previous research (Kulke, 2019) to  $-0.2$  to  $1$  s around the target stimulus.<sup>2</sup> Trials were rejected, when the maximum voltage was larger than  $\pm 100$   $\mu$ V, a slope larger than  $50$   $\mu$ V occurred or the deviation from the mean distribution exceeded 5. A repeated measures ANOVA comparing numbers of excluded trials between condition showed an effect of go/no-go condition on excluded trials,  $F(1, 39) = 31.09$ ,  $p < .001$ , with more excluded trials in the Go ( $M = 12.5$ ,  $SD = 8.05$ ) than in the no-go condition ( $M = 10.1$ ,  $SD = 6.39$ ), but this did not interact with the screen side on which stimuli appeared,  $F(1, 39) = 0.01$ ,  $p = .903$  or the expression,  $F(2, 78) = 0.112$ ,  $p = .894$ , and there were no main effects of side,  $F(1, 39) = 0.743$ ,  $p = .394$ , expression,  $F(2, 78) = 0.274$ ,  $p = .761$ , interaction of side and expression,  $F(2, 78) = 0.375$ ,  $p = .689$ , or three-way interaction,  $F(2, 78) = 1.293$ ,  $p = .280$ . This suggests that go trials were more often excluded due to noise than no-go trials, although the difference was small (on average 2 trials).

Areas of interest for ERP components were based on previous research. The P1 was quantified in two lateral parieto-occipital clusters (left: PO7, PO3, and O1, right: PO8, PO4, and O2) and its peak amplitude and latency was determined within 100–180 ms after target onset, based on comparable overt attention shift studies (Kulke et al., 2016a). In correct response trials, the mean EPN amplitude was extracted between 250 and 300 ms after stimulus onset in an occipito-parietal electrode cluster including electrodes O1, O2, P9, P10, PO7, and PO8 (Kulke, 2019); the mean LPC amplitude in a time window between 400 and

<sup>2</sup>Note that we originally planned to extract a short time interval of 180 ms for saccades, but that due to the ICA and for comparability reasons, we decided to extract all components within the larger interval.

600 ms after stimulus onset in an occipito-parietal electrode cluster including Pz, POz, PO3, and PO4 (Kulke, 2019); the mean N170 amplitudes were quantified in a time window between 130 and 200 ms after stimulus onset in a posterior electrode cluster (P7, P8, PO7, PO8, PO3, PO4, PO5, PO6) (Hinojosa et al., 2015). The mean no-go N2 was determined only for correct no-go trials between 200 and 350 ms in a fronto-central electrode cluster (Fz, F3, F4, Cz, C3, C4, FCz), based on previous research (Hepsomali et al., 2019; Righi et al., 2009; Sehlmeier et al., 2010). The frontal response was quantified between 100 and 180 ms in a frontal cluster (F3, FC5, FC3, FC1, C3, F4, FC2, FC4, FC6, C4).

## 2.6 | Statistical analysis

The statistical analysis was conducted as preregistered with the Open Science Framework (<https://osf.io/4kscq>) unless noted otherwise and performed using R (R Core Team, 2013, version 3.4.4.). Repeated measure ANOVAs were conducted using the ezANOVA function version 4.4–0 (Lawrence, 2016, version 4.4-0) to investigate effects of expression (happy, angry, and neutral) and task (go/no-go) on saccade latencies, error rates, and ERP amplitudes (as well as latency in the case of the P1). To investigate effects of different personality traits (Supporting Information A), linear regression analysis using the lm function and linear mixed-effects regression models (LMMs) using the lme function (Bates et al., 2015) were conducted. Follow-up *t* tests were performed using the *t* test function. Assumptions for all statistical models (depending on the test: sphericity, homoscedasticity, and normal distribution) were tested based on indications by Field et al. (2012). Although the assumptions were not met for every analysis, statistical models used in this study were relatively robust against such violations. Assumptions on variable types and nonzero variance in predictor variables were mostly fulfilled. Nevertheless, *p* values should be interpreted with caution. Since error rates were measured as probabilities between 0 and 1, they do not fit these assumptions in the current sample due to a natural zero point and constrained data. Therefore, an additional, non-preregistered binary logistic regression analysis was computed using the logReg function to determine whether the likelihood of an incorrect answer is greater given higher social anxiety or BIS-15 scores. A generalized eta squared ( $\eta^2_G$ ) was computed as an effect size for statistical models using the ezANOVA command. A correlation coefficient was calculated as an estimate of effect size, using the rcontrast function in R programmed by Field and Colleagues (2012) and Cohen's *D* was computed for post hoc *t* tests, both based on interpretations by Cohen (1988). Note that we preregistered to test directional hypotheses one-tailed and nondirectional

hypotheses two-tailed. For simplification, two-tailed results are reported in the manuscript with a cut-off value of  $p < .10$  for directional and  $p < .05$  for nondirectional hypotheses. In addition to the preregistered analyses, Bayes factors (BFs) were calculated with the respective commands lmBF and ttestBF (Morey & Rouder, 2015), to investigate in which direction and to what extent the probabilities for null hypothesis and alternative hypothesis differ. To investigate if the no-go-N2 amplitude could be correctly interpreted as an inhibition marker, differences between go and no-go conditions were explored with a *t* test using the *t* test function.

## 3 | RESULTS

Means, SDs, and 95% confidence intervals for the observed effects are reported in Table 1.

### 3.1 | Eye tracking

The current study used eye tracking to investigate the mechanisms of overt and covert emotion-driven attention. Since behaviorally overt and covert shifts of attention differ, with the former involving execution of a saccade and the latter involving inhibition of eye movements, different measures were used to test the effect of emotion on no-go and go conditions. To this end, when participants did make an overt shift of attention (go condition), the latency of saccades was compared between emotional expressions. When participants inhibited a saccade instead (no-go condition), the error rate was compared across emotion conditions.

#### 3.1.1 | Saccade latencies

Overall saccade latencies in the go condition (Figure 1) were significantly affected by expression,  $F(2, 78) = 2.845$ ,  $p = .064$ ,  $BF = 0.787$ ,  $\eta^2 = 0.001$  (note the cut-off *p* value of 0.10 due to preregistered one-sided testing). Planned follow-up *t* tests showed no significant difference between the angry and neutral faces,  $t(39) = -1.234$ ,  $p = .225$ ,  $BF = 0.345$ ,  $d = 0.039$  and between angry and happy faces,  $t(39) = -1.181$ ,  $p = .245$ ,  $BF = 0.326$ ,  $d = 0.045$ . However, there was a significant difference in saccade latencies between the happy and neutral faces,  $t(39) = -2.351$ ,  $p = .024$ ,  $BF = 1.957$ ,  $d = 0.085$ .

#### 3.1.2 | Error rates

Overall, errors, i.e., accidental eye movements in the no-go condition, occurred in 1.59% of trials ( $SD = 2.23\%$ ). Error

**TABLE 1** Means, SDs, and CIs of the observed effects

	Mean	SD	95% CI
Saccade latency (s)			
Angry	0.367	0.053	[0.350, 0.384]
Neutral	0.369	0.053	[0.353, 0.386]
Happy	0.365	0.053	[0.348, 0.382]
Error rates (proportion)			
Happy	0.099	0.060	[0.080, 0.119]
Neutral	0.092	0.050	[0.076, 0.108]
Angry	0.095	0.049	[0.079, 0.111]
P1 latency (ms)			
Happy	117.4	9.671	[114.3, 120.5]
Neutral	118.5	10.788	[115.1, 122.0]
Angry	116.4	9.424	[113.4, 119.4]
P1 amplitude ( $\mu$ V)			
Happy	2.331	2.080	[1.666, 2.996]
Neutral	2.299	2.023	[1.652, 2.946]
Angry	2.313	1.964	[1.685, 2.941]
Frontal response amplitude 100–180 ms ( $\mu$ V)			
Happy	2.004	1.179	[1.627, 2.380]
Neutral	1.927	1.154	[1.558, 2.295]
Angry	1.932	1.087	[1.585, 2.278]
Go	2.061	1.231	[1.667, 2.455]
No-go	1.847	1.081	[1.501, 2.193]
N170 amplitude ( $\mu$ V)			
Happy	-2.228	2.184	[-2.928, -1.530]
Neutral	-2.125	2.144	[-2.810, 1.439]
Angry	-2.174	2.083	[-2.840, -1.508]
Go	-2.387	2.332	[-3.133, -1.641]
No-go	-1.965	1.988	[-2.600, -1.329]
EPN amplitude ( $\mu$ V)			
Happy	-0.524	2.858	[-1.438, 0.390]
Neutral	-0.264	2.850	[-1.175, 0.648]
Angry	-0.555	2.666	[-1.407, 0.298]
Go	-0.742	2.992	[-1.699, -0.215]
No-go	-0.153	2.727	[-1.025, 0.720]
LPC amplitude ( $\mu$ V)			
Happy	5.361	1.955	[4.736, 5.986]
Neutral	5.248	1.811	[4.669, 5.827]
Angry	5.338	1.827	[4.754, 5.923]
Go	8.228	2.516	[7.424, 9.033]
No-go	2.403	1.531	[1.913, 2.893]

rates were unaffected by expression,  $F(2, 78) = 0.797$ ,  $p = .454$ ,  $BF = 0.150$ ,  $\eta^2 = 0.003$ . Planned follow-up  $t$  tests showed no significant difference of error rates between

the happy and neutral condition,  $t(39) = 1.119$ ,  $p = .270$ ,  $BF = 0.305$ ,  $d = 0.129$ , between the angry and neutral condition,  $t(39) = 0.536$ ,  $p = .595$ ,  $BF = 0.195$ ,  $d = 0.052$ , or between the angry and happy condition,  $t(39) = -0.776$ ,  $p = .443$ ,  $BF = 0.226$ ,  $d = 0.083$ .

Similar results were found with an exploratory logistic regression analysis predicting response (correct or incorrect) from expression category,  $\chi^2(2) = 2.331$ ,  $p = .312$  with  $R^2 < 0.001$ , which uses the binary data structure (i.e., codes for each trial whether the response was correct or incorrect) instead of averaging across data samples to compute proportions and is therefore less prone to model assumption violations.

### 3.2 | Neural effects (ERPs)

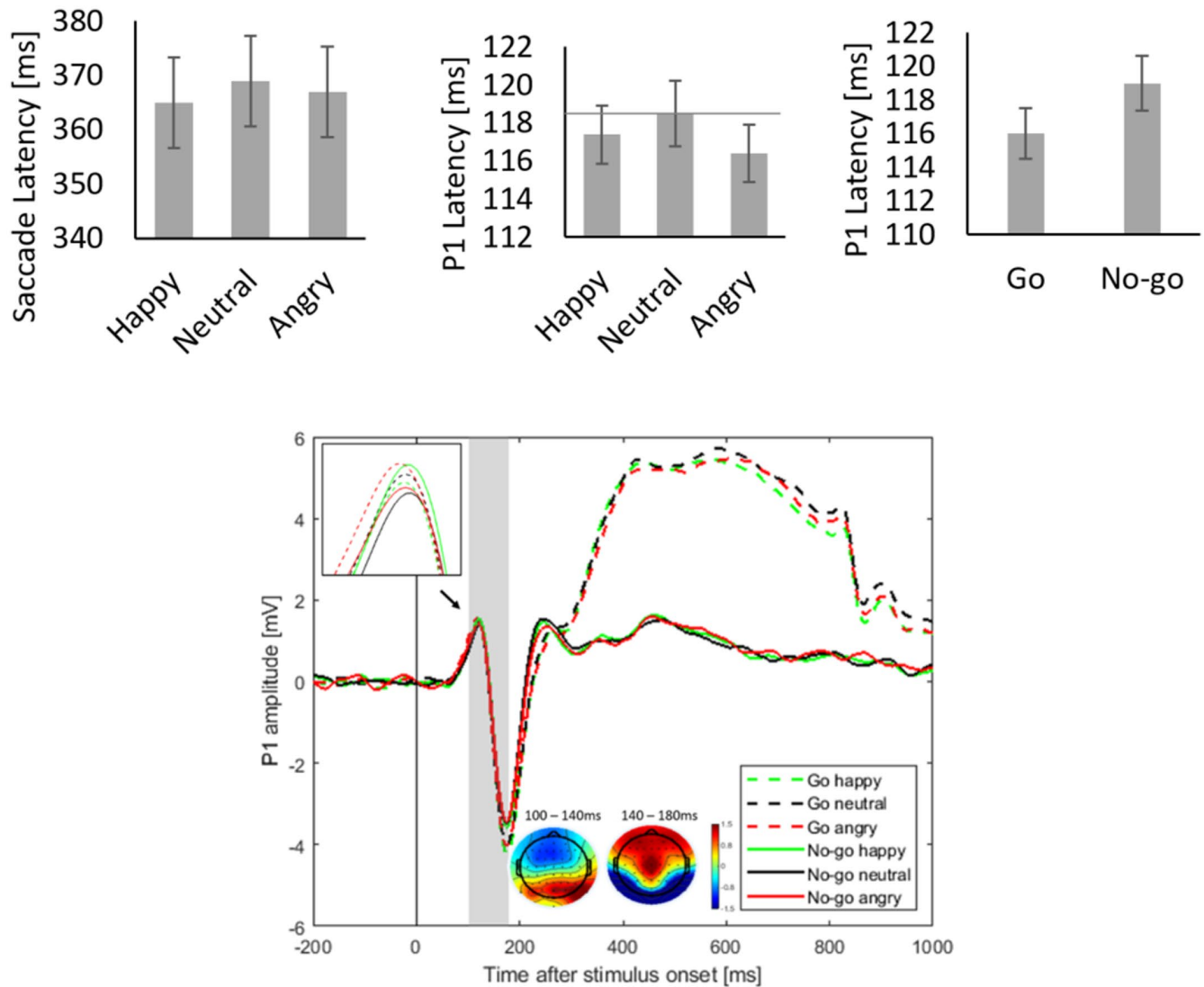
The first aim of the study was to identify the neural differences between overt and covert attention shifts to faces with different expressions. In the following, all latencies are reported in ms and all amplitudes in  $\mu$ V.

#### 3.2.1 | P1 latency

The P1 latency (Figure 1) was significantly affected by expression,  $F(2, 78) = 3.320$ ,  $p = .041$ ,  $\eta^2 = 0.006$  (note however,  $BF = 0.380$ ) and task,  $F(1, 39) = 7.819$ ,  $p = .008$ ,  $\eta^2 = 0.012$ ,  $BF = 10.705$ , with no significant interaction,  $F(2, 78) = 0.667$ ,  $p = .516$ ,  $\eta^2 = 0.002$ ,  $BF = 0.141$ . Wave plots and topographical plots are displayed in the bottom panel of Figure 1. The planned follow up  $t$ -tests showed a significant difference between angry and neutral faces,  $t(39) = -2.738$ ,  $p = .009$ ,  $BF = 4.355$ ,  $d = 0.210$ . However, neither the difference between happy and neutral,  $t(39) = -1.280$ ,  $p = .208$ ,  $BF = 0.364$ ,  $d = 0.109$ , nor the difference between happy and angry,  $t(39) = -1.224$ ,  $p = .229$ ,  $BF = 0.341$ ,  $d = 0.160$ , reached statistical significance.

#### 3.2.2 | P1 amplitude

P1 amplitude showed no overall effect of expression,  $F(2, 78) = 0.116$ ,  $p = .890$ ,  $\eta^2 < 0.001$ ,  $BF = 0.047$ , task,  $F(1, 39) = 0.046$ ,  $p = .831$ ,  $\eta^2 < 0.001$ ,  $BF = 0.143$ , or an interaction between task and expression,  $F(2, 78) = 1.859$ ,  $p = .162$ ,  $\eta^2 < 0.001$ ,  $BF = 0.247$ , on the P1 amplitude. Planned follow-up  $t$  tests showed neither significant differences between happy and neutral faces,  $t(39) = 0.507$ ,  $p = .615$ ,  $BF = 0.192$ ,  $d = 0.016$ , nor between the neutral and angry faces,  $t(39) = 0.233$ ,  $p = .817$ ,  $BF = 0.175$ ,  $d = 0.007$ , nor between the angry and happy faces,  $t(39) = -0.238$ ,  $p = .813$ ,  $BF = 0.175$ ,  $d = 0.011$ .



**FIGURE 1** Upper panel: Mean latency of saccades (left panel) and P1 component (center panel), for happy, neutral and angry faces as well as mean P1 latency for Go and No-go conditions (right panel). Error bars indicate 2 standard errors (SE) around the mean. The horizontal line signifies the neutral condition, to which the emotional expressions were compared. Bottom panel: Grand average wave plot, contrasted for happy, neutral, and angry faces in the go (solid lines) and no-go (dashed lines) task. The embedded topographical plots depict the grand average scalp distribution between 100–140 and 140–180 ms after target onset. The gray bar represents the analyzed time window (100–180 ms)

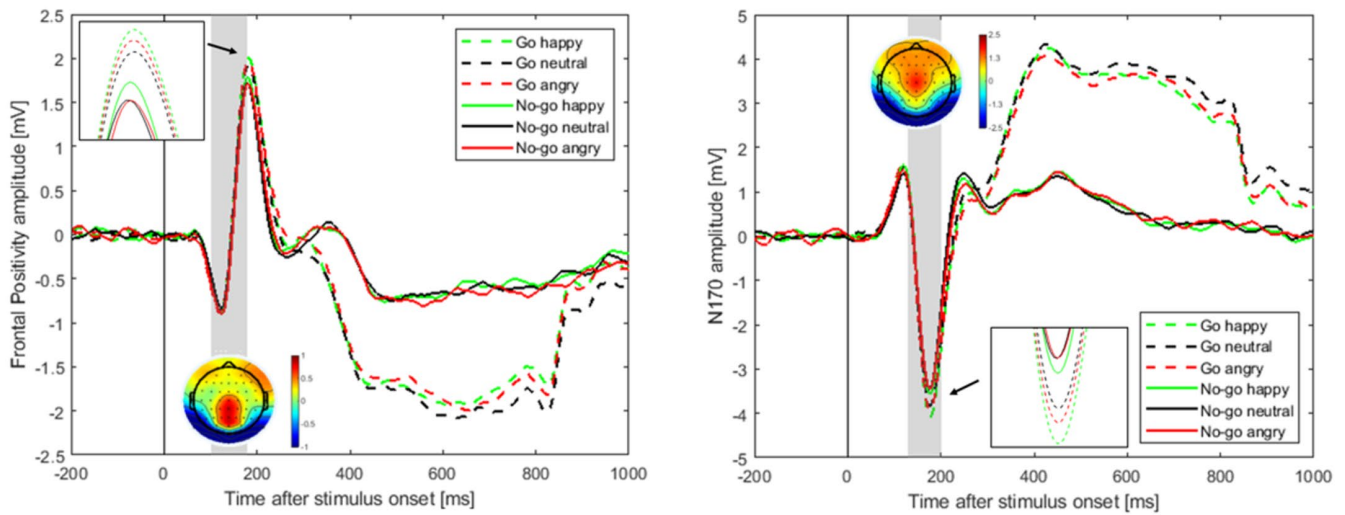
### 3.2.3 | Frontal response 100–180 ms

ERP peak amplitudes in frontal regions (Figure 2) showed a significant effect of task,  $F(1, 39) = 5.860$ ,  $p = .020$ ,  $\eta^2 = 0.008$ ,  $BF = 194.849$ , but no significant effect of expression,  $F(2, 78) = 1.323$ ,  $p = .272$ ,  $\eta^2 < 0.001$ ,  $BF = 0.090$ , and no significant interaction of task and expression,  $F(1, 78) = 0.604$ ,  $p = .549$ ,  $\eta^2 < 0.001$ ,  $BF = 0.102$ . Mean amplitudes were larger in the go compared to the no-go condition. The planned follow up  $t$  tests showed no significant difference between the happy and the neutral,  $t(39) = -1.693$ ,  $p = .098$ ,  $BF = 0.629$ ,  $d = 0.066$ , nor between the neutral and angry faces,  $t(39) = -0.096$ ,  $p = .924$ ,  $BF = 0.171$ ,  $d = 0.005$  or between the happy and angry faces,  $t(39) = -1.357$ ,  $p = .183$ ,  $BF = 0.398$ ,  $d = 0.064$ .

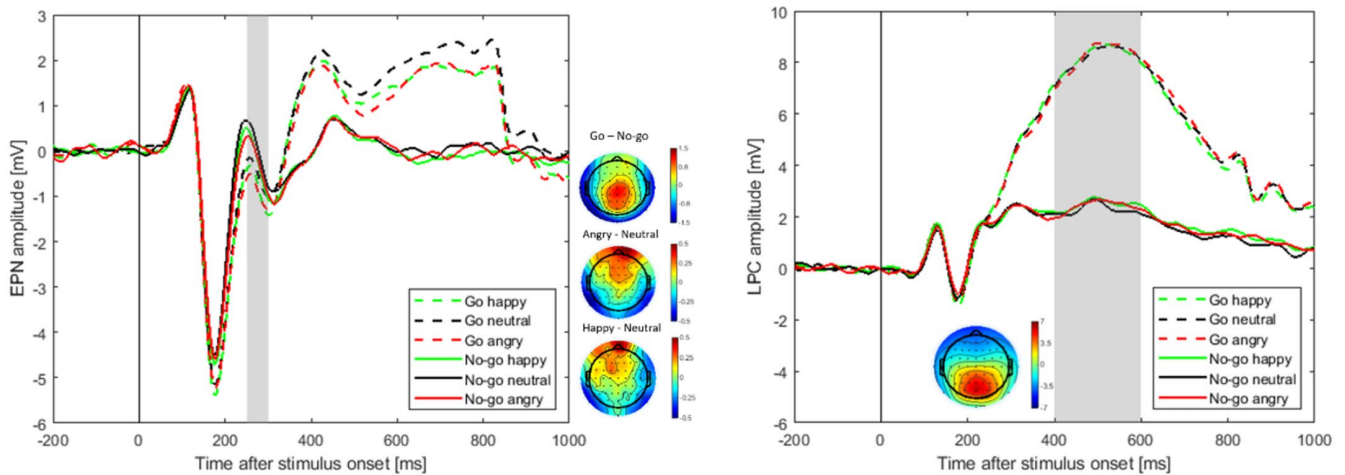
### 3.2.4 | N170

The N170 amplitude (Figure 2, right panel) showed no significant effect of expression,  $F(2, 78) = 1.152$ ,  $p = .321$ ,  $\eta^2 < 0.001$ ,  $BF = 0.068$ , nor a significant interaction between emotion category and condition,  $F(2, 78) = 0.466$ ,  $p = .630$ ,  $\eta^2 < 0.001$ ,  $BF = 0.098$ . However, there was a significant main effect of task,  $F(1, 39) = 9.439$ ,  $p = .004$ ,  $\eta^2 = 0.009$ ,  $BF = 46.841$ . Planned follow up  $t$  tests showed significantly more negative amplitudes in the go than the no-go trials,  $t(39) = -3.072$ ,  $p = .004$ ,  $BF = 9.270$ ,  $d = 0.180$ . But there was no significant difference between the happy and neutral faces,  $t(39) = -1.636$ ,  $p = .110$ ,  $BF = 0.578$ ,  $d = 0.048$ , no difference between the neutral and angry faces,  $t(39) = -0.710$ ,





**FIGURE 2** Topographical plot of all electrodes and wave of the electrode locations extracted to analyze the frontal positivity (left) and the N170 (right). The gray vertical bars represent the analyzed time windows (100–180 ms after stimulus onset for the frontal response and 130–200 ms for the N170). The embedded topographical plots depict the grand average scalp distribution within the analyzed time windows



**FIGURE 3** Topographical plots of all electrodes and wave of the electrode locations extracted to analyze the EPN (left panel) and LPC (right panel). The gray vertical bars represent the analyzed time windows (250–300 ms after stimulus onset for EPN and 400–600 ms for the LPC). The topographical plots in the center display the difference between go and no-go conditions, angry and neutral conditions, and happy and neutral conditions within the EPN time window. The topographical plot in the right panel displays the grand average within the LPC time window across all conditions

$p = .482$ ,  $BF = 0.216$ ,  $d = 0.023$ , nor between the angry and happy ones,  $t(39) = 0.756$ ,  $p = .454$ ,  $BF = 0.223$ ,  $d = 0.026$ .

### 3.2.5 | EPN

EPN amplitude (Figure 3, left panel) was significantly affected by expression,  $F(2, 78) = 6.796$ ,  $p = .002$ ,  $\eta^2 = 0.002$  (note however  $BF = 0.311$ ) and by task,  $F(1, 39) = 6.995$ ,  $p = .012$ ,  $\eta^2 = 0.011$ ,  $BF = 11,021.88$ , but there was no significant interaction,  $F(2, 78) = 0.295$ ,  $p = .746$ ,  $\eta^2 < 0.001$ ,  $BF = 0.092$ . Follow up planned  $t$  tests revealed significantly more negative amplitudes in response to happy than to neutral

faces,  $t(39) = -3.100$ ,  $p = .004$ ,  $d = 0.091$ ,  $BF = 9.867$ , and in response to angry compared to neutral faces,  $t(39) = -3.316$ ,  $p = .002$ ,  $d = 0.105$ ,  $BF = 16.662$ . Differences between happy and angry faces were not significant,  $t(39) = -0.349$ ,  $p = .729$ ,  $d = 0.011$ ,  $BF = 0.181$ . Further, go trials elicited larger negativities than no-go trials within the EPN time window,  $t(39) = -2.645$ ,  $p = .012$ ,  $d = 0.203$ ,  $BF = 3.562$ .

### 3.2.6 | LPC

LPC amplitude (Figure 3, right panel) was significantly affected by task,  $F(1, 39) = 362.20$ ,  $p < .001$ ,  $\eta^2 = 0.660$ ,



$BF > 1,000,000$ , with larger amplitudes in go, than in no-go trials. There was no main effect of expression,  $F(2, 78) = 1.192$ ,  $p = .309$ ,  $\eta^2 < 0.001$ ,  $BF = 0.045$ , and no significant interaction,  $F(2, 78) = 0.373$ ,  $p = .690$ ,  $\eta^2 < 0.001$ ,  $BF = 0.085$ . Planned follow up  $t$  tests showed significantly larger amplitudes in the go than the no-go condition,  $t(39) = 19.032$ ,  $p < .001$ ,  $d = 2.555$ ,  $BF > 1,000,000$ . There was no significant difference between the happy and neutral faces,  $t(39) = 1.321$ ,  $p = .194$ ,  $d = 0.060$ ,  $BF = 0.381$ , nor between the angry and neutral ones,  $t(39) = 1.172$ ,  $p = .250$ ,  $d = 0.047$ ,  $BF = 0.322$  and the angry and happy faces,  $t(39) = -0.329$ ,  $p = .744$ ,  $d = 0.012$ ,  $BF = 0.179$ .

## 4 | DISCUSSION

The current study aimed to investigate the effect of emotional facial expression on the neural mechanisms of covert and overt shifts of attention to faces, as well as their relation to personality traits. In summary, the latency of saccades and of the P1 was significantly affected by the expression of the peripheral faces, although Bayesian statistics suggest that this effect is marginal. Saccades were faster towards positive (and marginally towards negative) than towards neutral faces. P1 responses were faster towards negative (and marginally towards positive) than neutral faces. In all other components—except for the EPN—only a main effect of task was found, with larger ERP amplitudes for the go compared to the no-go condition. On the EPN, we found a significant effect of emotional expression with larger responses to emotional than neutral faces and a significant effect of task. Interestingly, effects of facial expression and of condition (go, i.e., overt shift versus. no-go, i.e., covert shift) did not interact on any measures, confirmed by BFs that were considerably below the cut off criterion of  $BF < 0.3$ . This suggests that emotion-driven attention is comparable between overt and covert shifts.

### 4.1 | Differences in ERP responses between go and no-go conditions

We found that the P1 amplitude was comparable for covert and overt shifts, in line with previous overt attention shift research (Kulke et al., 2016a) indicating that early visual/perceptual processes are similar for the two types of attentional shift (Kulke, 2019; Kulke et al., 2016a). However, in later ERP components, several *differences in neural responses between go and no-go conditions* were found. Across all later components examined here, larger response amplitudes were found in go than in no-go conditions (as detected on the early frontal positivity, the N170, the EPN, and the LPC). Only the N2 amplitude was larger in response to no-go compared to go trials, as expected (Supporting Information A).

A difference between covert and overt attention tasks is in line with previous research (Bokura et al., 2001; De Haan et al., 2008; Kulke et al., 2016a; Nobre et al., 2000). The current study suggests that neural responses reflecting perceptual processing may be attenuated when an eye movement needs to be inhibited, while only inhibitory responses are enhanced. This effect is unlikely to be related to eye-movement artifacts. Firstly, artifacts were removed using ICA. Secondly, effects were also found in posterior regions, which would only be marginally affected by eye movements. Furthermore, effects were found both on positive ERPs (e.g., frontal positivity, LPC) as well as on negative components (N170). Due to the dipole structure underlying ERP measurements, it is possible that the frontal response reflects the other end of a dipole to occipital responses (for a discussion of this issue, see also Kulke et al., 2016a), as response amplitudes are larger, i.e., more negative for the N170 and more positive for the frontal response in go than in no-go trials. However, interestingly, no such effects are found on the P1, which was measured in the same time window as the frontal response (100–180 ms after target onset), while the time window of the N170 only partially overlaps with the frontal response window (130–200 ms). Future research could further disentangle these observed scalp potentials through source analysis. Furthermore, the frontal positivity may be related to the N2, which was measured at a later time in the current study, but whose beginning may overlap with the peak of the frontal positivity according to the wave plots. However, the findings still suggest that overall response amplitudes are enhanced in go compared to no-go conditions. If eye-movement artifacts caused the effect, the polarity shift due to the eye movement would only be directed either towards negative or positive directions, but not differentially effect different time windows. Finally, eye movements induce a positive artifact on the ipsilateral and a negative one on the contralateral side. However, all electrode clusters were selected symmetrically, with equal numbers of electrodes in each hemisphere. Therefore, the observed effects most likely reflect distinct neural processes underlying covert and overt shifts of attention.

One possible explanation is that stimuli that one cannot look at are generally processed less intensively than those that can be viewed. This way, the brain may be favoring objects, from which it can derive more information through the execution of eye movements, as is the case in the go task. Alternatively, the effort required to inhibit an eye movement in no-go tasks may deplete processing resources, leaving a smaller processing capacity for neural responses to the stimuli. This would be in line with the “Premotor Theory of Attention,” suggesting that attention automatically facilitates actions such as saccades towards a location (Eimer et al., 2005; Sheliga et al., 1994), and these automatically generated motor responses need to be inhibited.

Another aspect to be considered is that the presentation of targets in no-go trials was constantly peripheral, while there was a change between peripheral and foveal presentation in go trials due to the change in gaze position. Previous research suggests that emotion perception may differ between fovea and peripheral visual field (Rigoulot et al., 2011). In the current study, however, the average latency of eye movement onsets was longer than 350 ms, and all ERPs—except for the LPC—were computed in time windows before the saccades. Therefore, these ERPs should be unaffected by differences between peripheral and foveal stimulation. As ERP differences between go and no-go conditions were not limited to the LPC and as no interaction occurred between condition and expression at LPC level, the observed effects are unlikely related to differences in foveal and peripheral stimulation.

In general, neural responses seem significantly larger in response to stimuli that participants can overtly shift to, compared to those they can only covertly attend to.

## 4.2 | Effects of emotional facial expression

The EPN was significantly enhanced in response to happy and angry compared to neutral faces, in line with previous research with (Kulke, 2019) and without eye movements (Schacht & Sommer, 2009; Schupp et al., 2004). This confirms that participants perceived differences between emotional and neutral facial expressions in the current study.

*Facial expression* had a significant effect on *P1 latency and saccade latency*, with both latencies being shorter for emotional compared to neutral faces. However, this effect was marginal based on Bayesian analyses. It should be noted that effects of emotional expression were considerably smaller than effects of go/no-go condition. These effects seem to be more variable and may require more power and larger sample sizes to be detected. They should therefore not be considered on an individual subject level but only on a group level. Interestingly, despite the *latency* effects in the current study, the *amplitude* of the P1 was unaffected by facial expression, with Bayesian statistics suggesting that a null effect is 21 times more likely than a significant effect. The lack of emotion-driven attention effects on the P1 amplitude in our study is in line with some covert attention studies (Frühholz et al., 2011; Rossignol et al., 2012), while contradicting others (Pourtois et al., 2005; Rellecke et al., 2012; Vlamings et al., 2009). These heterogeneous findings are a recent topic of scientific discussion (Schindler & Bublatzky, 2020), with the current study adding to this discussion by suggesting a lack of emotion effects on P1 amplitude in attention shift paradigms involving overt and covert shifts. The finding that emotional content can have small but significant effects on P1 latency but not on P1 amplitude suggests that emotional content might only effect the processing speed at early neural

level, but not lead to a deeper processing as indicated by higher response amplitudes.

Previous research also found mixed results in regards to whether or not *saccades* are affected by emotional content (Bannerman et al., 2012; Kissler & Keil, 2008; Kulke, 2019; Nummenmaa et al., 2006). In particular, the current results contrast the overt attention shift study by Kulke (2019), which showed that fast and reflexive eye movements were unaffected by emotional content. In contrast to this previous study, in which eye movements were purely reflexive, the current study involved a paradigm in which participants had to evaluate first whether they should make an eye movement or not. Therefore, the eye movements needed to be explicitly controlled and were less reflexive. Our results confirm the idea that explicit control was required due to increased task difficulty, as eye movements were considerably slower (mean saccade latency between 365 and 369 ms) than in the study by Kulke (2019) (188 ms). Considering the differences in saccade latencies, while ERP latencies were comparable between both studies, more ERP components occurred before saccade onset in the present study. Therefore, more neural processing stages were completed before saccades were executed. Due to this delay, in the current study, later neural responses could have impacted the eye movements, while the fast reflexive eye movements in the previous study (Kulke, 2019) could not have been affected by these later processing steps. It is therefore possible, that eye movements are only affected by emotional facial expressions when certain neural processing of these expressions has occurred before saccade onset. In particular, the EPN occurred before saccade onset in the current study, while it was elicited after saccade onset in the study by Kulke (2019). This component also most reliably differentiated between facial expressions in both studies. Such a cortical differentiation, measured through the EPN, may affect saccade execution through feedback connections with the Superior Colliculus, which is highly linked with cortical areas, particularly the visual cortex. Taken together, the findings suggest that fast and reflexive saccades remain unaffected by emotional expressions; yet, if saccades are inhibited long enough for neural processing of emotional content to occur (i.e., until after the EPN), the subsequent eye movements are influenced by these neural processes. Slower, controlled eye movements can therefore be affected by emotional content, while fast, reflexive ones cannot.

## 4.3 | Methodological factors influencing saccade latency

Several factors may have led to the overall slower eye movements in the current study. In contrast to previous work (Kulke et al., 2016a), go and no-go trials were randomized within and not between experimental blocks. Therefore,

an additional processing effort was required in each trial to evaluate whether the task is to make an eye movement or not. Furthermore, in comparison to studies using a comparable experimental design, target stimulus and cue (i.e., colour change) were presented simultaneously (Kissler & Keil, 2008; Wieser et al., 2009). The evaluation of the cue may have occupied processing resources, leading to longer overall processing. Additionally, the color change in the fixation center may additionally have attracted attention to the center thereby slowing the response to the periphery. Studies showed that competition between central and peripheral stimuli can decelerate both eye movements and neural responses (Kulke et al., 2020). Therefore, the central competition for attention may have slowed responses in the current paradigm. The visual change in the fovea may also have induced simultaneous P1 responses, which may have overshadowed any emotion effects in the current study. To disentangle potential explanations for the deceleration of saccades, the use of a block design for go and no-go trials in future research could minimize these distractions (see Kulke et al., 2016a). As the shift latency is decelerated in the current task, block designs and interleaved designs could furthermore be directly compared. In particular, it would be interesting to include a block in which participants are allowed to move their eyes freely, allowing an investigation of natural eye movements. While the current study implemented a highly controlled comparison of covert and overt shifts of attention and instructed participants when to move their eyes (to ensure that sufficient numbers of trials with and without eye movements were recorded), allowing both types of shifts closely simulates natural gaze conditions and thus provides one additional step in comparing controlled laboratory tasks and natural real-world eye movements.

#### 4.4 | Conclusion

In summary, neural mechanisms significantly differed between covert and overt attention shifts in regard to various ERPs. Emotional facial expressions affected the EPN amplitude, the P1 latency and the saccade latency but did not interact with overt and covert conditions. Only slow saccades, such as measured in the current study, but not fast reflexive saccades, such as measured by Kulke (2019), seem to be affected by emotional expressions, with emotion effects being rather small, as neural processing of emotion may be required before saccade onset for emotion effects to occur. The current study suggests that neural responses are significantly enhanced when people move their eyes towards a face of interest, compared to when they need to inhibit such eye movements. This finding indicates that the inhibition of gaze towards other people's faces, which is commonly observed

during everyday life, has a significant impact on the magnitude of neural responses to these faces, although it does not seem to impair classification of their emotional expressions. Furthermore, our results suggest that emotional expressions automatically capture attention and thereby enhance neural responses regardless of whether shifts of attention are accompanied by eye movements or not. The study is the first to implicate that effects of emotional expressions on early neural responses and saccades differ when people make reflexive eye movements, compared to when they explicitly control and delay eye movements towards faces. This highlights, once more, the relevance of studying overt attention under more realistic circumstances. In conclusion, the findings of our study indicate that the neuro-cognitive mechanisms of emotion-driven attention are independent of the overt or covert mode of the attention shift.

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#### CONFLICT OF INTEREST

The authors declare no conflict of interest.

#### AUTHOR CONTRIBUTIONS

**Louisa Kulke:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Software; Supervision; Visualization; Writing-original draft; Writing-review & editing. **Lena Brümmer:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Visualization; Writing-review & editing. **Arezo Pooremaeli:** Conceptualization; Funding acquisition; Methodology; Supervision; Writing-review & editing. **Annekathrin Schacht:** Conceptualization; Funding acquisition; Methodology; Resources; Supervision; Writing-review & editing.

#### DATA AVAILABILITY STATEMENT

The data will be published as supplement alongside the article.

#### ETHICS STATEMENT

The study abided by the ethics regulations of the Declaration of Helsinki and was approved by the local ethics committee of Georg-August University Göttingen. Written informed consent was obtained from participants before their participation in the study.

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## SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section.

Fig S1

Supplementary Material

Supplementary Material

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