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Visual competition attenuates emotion effects during overt attention shifts

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Abstract

Numerous different objects are simultaneously visible in a person's visual field, competing for attention. This competition has been shown to affect eye-movements and early neural responses toward stimuli, while the role of a stimulus' emotional meaning for mechanisms of overt attention shifts under competition is unclear. The current study combined EEG and eye-tracking to investigate effects of competition and emotional content on overt shifts of attention to human face stimuli. Competition prolonged the latency of the P1 component and of saccades, while faces showing emotional expressions elicited an early posterior negativity (EPN). Remarkably, the emotion-related modulation of the EPN was attenuated when two stimuli were competing for attention compared to non-competition. In contrast, no interaction effects of emotional expression and competition were observed on other event-related potentials. This finding indicates that competition can decelerate attention shifts in general and also diminish the emotion-driven attention capture, measured through the smaller effects of emotional expression on EPN amplitude. Reduction of the brain's responsiveness to emotional content in the presence of distractors contradicts models that postulate fully automatic processing of emotions.

KEYWORDS

attention, EEG, emotion, ERPs, eye-tracking

1 | INTRODUCTION

Humans need to focus their attention on relevant objects in order to react to them appropriately. This attention allocation is commonly accompanied by an eye-movement toward the object of interest, i.e., an overt shift (Nummenmaa et al., 2006). In many situations, there are several objects in the visual field competing for attention, requiring flexible shifts of attention between them. Shifts of attention in displays containing two or more stimuli (i.e., competition conditions) are guided by exogenous (or bottom-up) and endogenous (top-down) factors, such as the physical salience of stimuli or their emotional content, respectively. The current study focused on the latter, investigating how emotional content guides the allocation of attention to objects, either in the presence or absence of competition. We used eye-movements and event-related potentials (ERPs) as online indicators of information processing, impacted by emotion and attention.

Resolving the competition between objects requires humans to disengage from one object before being able to shift their attention to another object. Both non-clinical and clinical studies have been using eye-movement tasks such the fixation shift / gap-overlap paradigm (Atkinson et al., 1988, 1992; Atkinson & Braddick, 1985, 2012; Hood & Atkinson, 1993) to study attentional shifts. In this paradigm, a central stimulus is presented, followed by a peripheral target that either appears while the first stimulus is still visible (competition condition / overlap condition) or after it disappears (non-competition condition / gap condition). Eye-movement latencies toward the peripheral stimulus are measured, which reflect the ability to shift attention when a simple gaze shift is required (in the non-competition condition) and when disengagement from a central stimulus is required in addition to the gaze shift (competition condition). In addition to eye-movement metrics, such as the saccade latency, we also measured person-related factors. This was done, since individual differences in allocation of attention, based on non-clinical traits, have been demonstrated (Bradley et al., 2000; Mogg et al., 2004; Wieser et al., 2018) and may, therefore, modulate attention in the planned task as investigated in previous similar studies (Kulke, 2019; Kulke et al., 2021). Person-related factors were also considered in the current study and reported in Supplement B.

Examining event-related potentials (ERPs) in addition to eye-movements enables additional insights into covert attentional processes that cannot be uncovered through verbal reports or behavioral measures. Event-related potentials (ERPs) allow to study the time-course of attentional and emotional processes as well as their interactions. Studies combining EEG and eye-tracking enabled the investigation of overt attention shifts involving eye-movements (Huber-Huber et al., 2016; Kulke, 2015, 2019; Kulke et al., 2016a, 2016b; Weaver et al., 2017), and indicated that neural responses to attended stimuli differ between overt and covert attention shifts. In particular, frontal ERP components were more enhanced during covert than during overt shifts, suggesting that cognitive control is required to inhibit eye-movements (Kulke et al., 2016a). Furthermore, several ERPs to emotional and non-emotional face stimuli were amplified during overt compared to covert attention shifts (Kulke et al., 2021), including the N170 (negativity around 170 ms after stimulus onset mainly related to face processing), EPN (Early Posterior Negativity, related to processing of emotional content), and LPC (Late Positive Complex related to task difficulty, higher order processing and emotion processing) (Junghöfer et al., 2006; Rellecke et al., 2011, 2012; Schacht & Sommer, 2009; Schupp et al., 2003, 2004). Of these components, there is robust evidence for effects of emotional expressions on the EPN and LPC (Batty & Taylor, 2003; Hinojosa et al., 2010; Hinojosa et al., 2015; Rellecke et al., 2012; Schacht & Sommer, 2009), although the LPC was unaffected by emotional content in a previous overt attention shifting task (Kulke et al., 2021). Evidence for emotion effects on earlier components such as the N170 and P1 (shown to be modulated by early attention) is rather mixed (for a recent review, see Schindler & Bublatzky, 2020), presumably due to boundary conditions that are yet not well understood. Two opposing accounts suggest that emotional stimulus content either draws attention automatically (e.g., Pourtois et al., 2004) or that it requires availability of attentional resources (Pessoa & Ungerleider, 2005). Studying overt shifts may help resolving ambiguities regarding early and late emotion-driven attention effects in the ERP literature. In particular, ERPs help to identify the time-course of emotion effects to determine if emotion effects automatically occur at an early processing level or only affect later responses. Employing an overt shift of attention paradigm additionally allows to examine whether early versus late emotional processing theories hold under more naturalistic conditions. Overt shifts are more natural than covert shifts as people are free to move their eyes in everyday life rather than being asked to keep fixating on a fixation point, as common in previous EEG research. If emotion effects occur very early during neural processing, this would be in line with accounts suggesting an early capture of attention through emotional content.

Simultaneous co-registered examination of stimulus-driven eye-movements and EEG signals can help to determine whether and how emotional processing and attentional allocation to one of several competing targets interact. However, previous co-registration studies have either examined only one of the two factors or have provided mixed results. Studies on overt attention shifts demonstrated effects of *competition* between targets on early attention-related ERPs and eye-movements (Kulke et al., 2020), with decelerated latencies when disengagement is required from competing targets. The role of *emotional expression*—reliably demonstrated to capture attentional resources—during overt attention shifts is less clear. While Kulke (2019) did not find effects of emotional expressions on purely reflexive saccades toward faces when no specific instructions were given where participants should look at, Kulke et al. (2021) showed effects of emotional facial expressions on latencies of the P1 and saccades in a go/no-go task. In their study, eye-movements were significantly slower compared to the study by Kulke (2019), as participants needed to process within each trial whether to make an eye-movement (go condition) or not (no-go condition). Therefore, slow-controlled saccades, which took place after emotion effects occurred in the ERPs, seemed to be affected by emotional expression, while fast reflexive saccades were not. If stimuli are competing for attention, eye-movements are slower and may, therefore, be more likely influenced by emotional content. However, such competition was not manipulated in previous studies on emotion-driven attention, which show mixed findings regarding early effects of emotion-driven attention (for a recent review, see Schindler & Bublatzky, 2020), reflected in ambiguity of theories (e.g., Pessoa & Ungerleider, 2005; Pourtois et al., 2004). As competition has also been shown to affect saccades and early ERPs, a direct comparison of competition and non-competition conditions can provide insights in the role that competition plays for emotion effects. However, *interactions* between competition and emotional expression effects have never been investigated during overt attention shifts. The current study aimed to fill this gap.

For this purpose, we presented a face from a pool of different identities with a neutral expression centrally to participants, gaze-contingently followed by a peripheral face from the same pool of identities showing either a neutral, happy, or angry expression. The peripheral face either appeared while the central face disappeared (non-competition condition) or while it remained visible (competition condition), allowing a manipulation of disengagement. In the previous literature, P1 and saccade latency were reliably affected by attentional competition. Effects of emotional content were unreliable on these measures, in particular during overt attention tasks. We, therefore, expected attention shift latency (measured through P1 and saccade latencies) to be significantly faster in non-competition than in competition conditions, but unaffected by emotional expressions. We expected the amplitude of the *early* P1 to be affected by competition, with shorter latencies in non-competition than in competition condition, but not by emotional expression. In contrast, we expected the *mid-latency* EPN to be more pronounced in response to emotional than to neutral faces, reflecting their emotion-driven attentional draw. We planned and preregistered to analyze potential interaction effects of emotion expression with disengagement on early components, but did not have a specific hypothesis regarding the effect, as it has not previously been studied. Due to the strong task-dependence of emotion effects at the LPC level, (Schindler & Bublatzky, 2020) and as no emotion effects were observed in a similar overt attention shift study, we expected the LPC to be affected by competition manipulation but not by emotional expression. Individual differences in the observed effects were investigated as preregistered. As our study failed to demonstrate the assumed differences, these results are reported in Supplement B.

2 | METHOD

2.1 | Participants

All methods and analyses were in line with the preregistration (https://osf.io/324ds) unless otherwise noted.

Sample size calculations for competition and emotion effects were conducted in G*Power (version 3.1.9.2) and a minimum sample size of 35 participants was determined and preregistered. Due to a sampling error, 40 participants were tested. However, identical analyses were conducted with the subset of the first 35 participants who were tested, leading to identical decisions about the pre-registered hypotheses. Therefore, data from all participants is reported in this manuscript. All participants (Mage = 22,4 years, SD = 3.19, range = 18–32, 9 male) were healthy (according to self-report) and volunteered to participate in the study after providing informed consent. Seven additional participants were tested but excluded because EEG data was incomplete (3), because of low eye-tracking data quality based on the criteria defined below (2) and because more than 50% of the data was missing after excluding noisy EEG and eye-tracking data (2). The study was conducted in line with the Declaration of Helsinki and approved by the local ethics committee.

2.2 | Procedure

After participants provided informed consent, the EEG electrodes were applied, and the eye-tracker was calibrated and validated using a 9-point calibration routine. Between experimental blocks, a one-point drift correction routine was implemented to ensure high quality of eye-tracking data throughout the experiment. The experiment was programmed in Python and PsychoPy (Peirce et al., 2019). Initially, a face (ellipsoid with a size of 4.5 × 7 cm, visual angle of 3.4° × 5°, 324 × 504 pixels) with a neutral expression was presented in the center of a white background on a liquid crystal display (LCD) computer screen. A small fixation cross (size: 40 pixels, 0.56 cm, 0.4°) was superimposed over the face. Participants were asked to fixate on the cross to ensure that gaze was stable at the onset of the peripheral target. After a random interval between 1500 and 2500 ms, if participants fixated within an area of 40 pixels (0.56 cm, 0.4°) around the fixation cross for at least 150 samples (at a sampling rate of 500 Hz this corresponds to 333.33 ms), a second face stimulus was presented peripherally, 5.6 cm (400 pixels, 4°) to the right or the left side. The presentation of the peripheral face was gaze contingent; therefore, the trial only proceeded when participants fixated on the central stimulus, and the central stimulus was presented for as long as necessary until the fixation criteria were fulfilled but at minimum for the random interval specified above. This means that if the participant fixated on the central stimulus at the end of the random interval, the trial immediately proceeded but if the participant did not fixate centrally at this time, the presentation of the central stimulus continued until a central fixation was detected as defined above, and only then the peripheral face appeared. The peripheral face either showed a happy, neutral, or angry expression (emotion). The peripheral face appeared while the central face remained visible (competition condition) or while the central face and the central fixation cross disappeared (non-competition condition, Figure 1). The side on which the peripheral target face appeared (left or right periphery) was counterbalanced within each participant, with each participant seeing each stimulus equally often on the left and right side. The peripheral face was presented for at least 700 ms and then disappeared when participants fixated within 40 pixels (0.56 cm, 0.4°) of the image for at least 150 samples and the next trial was initiated after 500 ms. Participants completed 12 blocks, with 80 trials presented per block, leading to overall 160 trials per condition.

After the experiment, participants completed the German version of the Behavioral Inhibition/Behavioral Avoidance Scale (BIS/BAS; [Strobel et al., 2001]), the "Reading Mind in the Eye" test (Baron-Cohen et al., 2001), the Autism Quotient Questionnaire (AQ; [Baron-Cohen et al., 2001]) and the SIAS questionnaire (Stangier et al., 1999). The questionnaires were implemented to investigate individual differences in the observed effects. As no such reliable differences were observed, detailed findings are reported in Supplement B. Participants received course credit or monetary reward in return for participation.

2.3 | Design and stimuli

Face stimuli were color images of 10 different individuals (5 male and 5 female) selected from the Karolinska Directed Emotional Faces database (Lundqvist et al., 1998), each displaying angry, neutral, and happy facial expressions. Stimuli were trimmed to exclude external features such as hair, ears, and clothing and controlled for luminance, if required (Hammerschmidt et al., 2017; Kulke, 2019). In a repeated measures design, emotional expression (happy, neutral, and angry), and competition condition (competition and non-competition) were manipulated within participants and questionnaire scores were compared between participants.

2.4 | Eye-tracking

A desktop-mounted eye-tracker (Eyelink 1000, SR Research, Ontario, Canada) recorded both eyes continuously throughout the experiment at a sampling rate of 500 Hz. Participants placed their head on a chin-rest to minimize head movements and to ensure an average viewing distance of 80 cm.

After completion of the experiment, the raw eye-tracking data was preprocessed in MATLAB version R2017a, based on previous research (Kulke, 2019). Gaze-position data from both eyes was averaged. Horizontal saccades were determined as a gaze change in x-position of more than 40 pixels between two subsequent samples and the latency of the first saccade toward the target face was determined within each trial. Noisy data was rejected including (1) trials with saccades occurring faster than 100 ms after stimulus onset as they are unlikely to

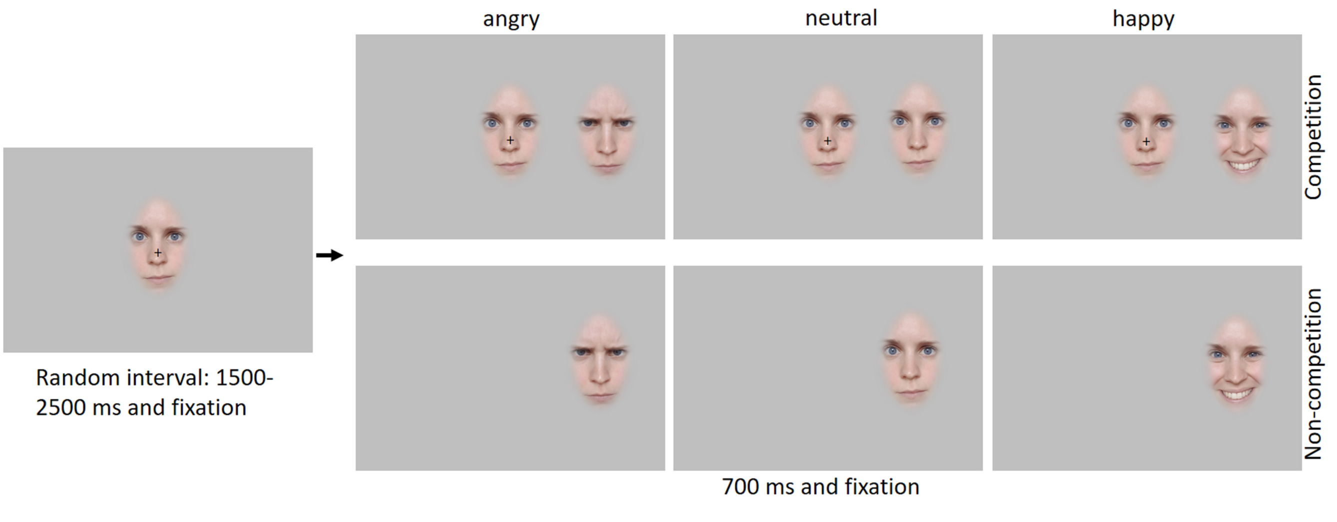

FIGURE 1 Trial sequence. In the beginning, a neutral face appeared in the center of the screen for a random interval of 1500 to 2500 ms. Once the participant fixated on it at the end of or after this interval, an angry, neutral, or happy face appeared in the periphery either while the central face was still present (competition) or after it disappeared (non-competition condition)

be target-related (2) saccades slower than 700 ms, (3) fixation more than 40 pixels from the fixation cross at trial onset, (4) excessive changes in fixation position, indicative of noisy data, (5) eye-movements to the incorrect side. On average, 793 trials entered the analysis per participant after exclusion criteria were applied ($SD = 103$, $min = 510$, $max = 958$).

2.5 | EEG

The EEG was recorded using ActiView707 BioSemi recording software for Linux 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), based on the extended 10–20 international system (Pivik et al., 1993) with the common mode sense electrode (CMS) and the driven right-leg electrode (DRL) as reference and ground electrodes and raw data without online filters was saved. Six external electrodes were added below the eyes (2), on the outer edges of the eyes (2) and on the left and right mastoids (2). Electrode offsets were kept below +/− 25 mV.

After completion of the experiment, preprocessing of EEG data was conducted in MATLAB version R2017a using functions of the EEGlab toolbox, based on previous research (Kulke, 2019; Kulke et al., 2016a). External channels were removed; the continuous data was baseline corrected using a 200 ms time interval. The data was filtered using second-order Butterworth bandpass filters with a high-pass boundary of 0.01 Hz and a low-pass boundary of 25 Hz. 50 Hz line noise was removed using the CleanLine plugin (Mullen, 2012). The data was re-referenced to the average reference and down-sampled from 512 to 500 Hz. The system delay between the trigger signal and the visual presentation on the computer monitor was determined as 24 ms, using a light-sensitive diode; triggers were shifted accordingly.

An Independent Component Analysis was conducted on a separate dataset, on which stronger high-pass filters of 1 Hz and a 40 Hz low-pass filter were applied. Epochs of −200 to 1000 ms around stimulus onset were extracted, on which 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 related to eye artifacts (vertical eye-movements, horizontal eye-movements, and blinks). Those ICs that were marked by both coders were rejected from the final dataset ($M = 2.7$ per participant, $SD = 1.4$, $\min = 1$, $\max = 8$). The weights from this ICA dataset were then applied to the original dataset. EEG data was epoched from −200 to +1000 ms around the onset of the peripheral target. Trials excluded based on the eye-tracking criteria were also excluded from the EEG analysis. Trials were further rejected, when (1) the maximum voltage was larger than +/−100 μV, (2) the slope at any point was larger than 50 μV, or (3) the deviation from the mean distribution exceeded 5 μV. ERP components were determined based on previous research. The peak amplitude and peak latency of the P1 were quantified in two lateral parieto-occipital clusters (left: PO7, PO3, O1, right: PO8, PO4, O2) within 100-180 ms after target onset, measured as the peak amplitude in the averaged electrode cluster within the predefined time-window, based on previous research (Kulke et al., 2016a). Note that previous research found comparable effects for fractional area latency and for peak latency measures in a similar task (Kulke et al., 2020), which is why only peak latency was used as a pre-registered measure in the current study. Mean amplitudes were calculated for the EPN between 250 and 300 ms after stimulus onset in an occipito-parietal electrode cluster (O1, O2, P9, P10, PO7, and PO8) and the LPC between 400 and 600 ms after stimulus onset in an occipito-parietal electrode cluster (Pz, POz, PO3, and PO4) (Kulke, 2019; Kulke et al., 2021).

2.6 | Statistical analysis

Statistical analyses were conducted in R (R Core Team, 2018). Effects of emotional expression (happy, angry, and neutral) and competition condition (competition or non-competition) on saccade latencies and ERPs were determined using repeated-measure ANOVAs using the ezANOVA function (Lawrence, 2016, version 4.4-0). Effects of personality traits were determined with linear regressions using the lm function and linear mixed-effects regression models (LMMs) using the lme function (Bates et al., 2015). Follow-up t-tests were performed using the t.test function. As follow-up tests were preregistered, no additional correction for multiple comparisons was implemented. Two-tailed p-values are reported here with a cut-off value of $p < .10$ for directional and $p < .05$ for non-directional hypothesis. In addition, Bayes Factors (BF) were calculated with the respective commands using the BayesFactor package in R (Morey & Rouder, 2015), to investigate in which direction and to what extent the probabilities for null hypothesis and alternative hypothesis differ. BFs larger than 1 were interpreted as evidence for the H1, BFs larger than 3 as substantial evidence for the H1. BFs smaller than 1 were interpreted as evidence for the H0, BFs smaller than 0.3 as substantial evidence for the H0. Assumptions of the used models were checked as required by the respective statistics, using the Shapiro–Wilk normality test, histograms, Q-Q-plots, homoscedasticity plots, and Mauchly's Test for Sphericity. The assumptions were fulfilled in most cases, with only small deviations in some conditions. We, therefore, decided to conduct the planned analyses as preregistered.

3 | RESULTS

Descriptive statistics are reported in Table 1.

3.1 | Saccade latency

There were significant main effects of emotion, $F(2, 78) = 6.79$, $p = .002$, $\eta^2 = .006$, but note $BF = .078$, and of competition condition, $F(1, 39) = 250.84$, $p < .001$, $\eta^2 = .420$, $BF > 1.000.000$ (Figure 2), but no significant interaction between emotion and competition conditions, $F(2, 78) = 1.23$, $p = .299$, $\eta^2 = .001$, $BF = 0.136$. Mean latency of saccades toward happy faces was significantly shorter than of saccades both toward angry, $t(39) = -2.25$, $p = .030$ and neutral faces, $t(39) = -4.09$, $p < .001$, $d = 0.200$, $BF = 125.181$. Latency did not differ between angry and neutral faces, $t(39) = -1.20$, $p = .236$, $d = 0.071$, $BF = 0.334$. Saccade latency was significantly longer in the competition than in the non-competition condition, $t(39) = 15.84$, $p < .001$, $d = 1.668$, $BF > 1.000.000$.

3.2 | ERPs

3.2.1 | P1 latency

There was significant effect of competition condition (Figure 2) on P1 latency, $F(1, 39) = 52.38$, $p < .001$, $\eta^2 = 0.183$, $BF > 1.000.000$, but no significant effect of emotion, $F(2, 78) = 0.43$, $p = .651$, $\eta^2 = .001$, $BF = 0.052$, and no significant interaction, $F(2, 78) = 0.22$, $p = .803$, $\eta^2 < .001$, $BF = 0.086$.

3.2.2 | P1 amplitude

There were no significant effects of emotion, $F(2, 78) = 0.45$, $p = .639$, $\eta^2 < .001$, $BF = 0.055$, of competition condition, $F(1, 39) = 1.33$, $p = .257$, $\eta^2 = .003$, $BF = 0.972$, and no interaction effect, $F(2, 78) = 1.31$, $p = .275$, $\eta^2 < .001$, $BF = 0.126$.

3.2.3 | EPN amplitude

There was a significant effect of emotion, $F(2, 78) = 14.20$, $p < .001$, $\eta^2 = .011$, $BF = 390.635$, as well as a significant interaction effect of emotional expression and competition condition, $F(2, 78) = 7.72$, $p < .001$, $\eta^2 = .003$, $BF = 66.699$, but no main effect of competition condition, $F(1, 39) = 0.16$, $p = .688$, $\eta^2 < .001$, $BF = 0.176$. EPN amplitudes were more negative for happy than angry faces, $t(39) = -2.17$, $p = .036$, $d = 0.106$, $BF = 1.383$, for happy than neutral faces, $t(39) = -4.86$, $p < .001$, $d = 0.262$, $BF = 1094.618$, and for angry than neutral faces, $t(39) = 3.46$, $p = .001$, $d = 0.154$, $BF = 24.080$. Interestingly, when considering competition conditions separately (Figure 3), there was no difference between happy and angry faces, $t(39) = -0.84$, $p = .409$, $d = 0.049$, $BF = 0.236$, or between angry and neutral faces, $t(39) = -1.42$, $p = .164$, $d = 0.078$, $BF = 0.431$, and a small difference between happy and neutral faces,

TABLE 1 Descriptive statistics

Condition	*M*	*SE*	95% *CI*
Saccade latency [s]			
Happy	0.183	0.004	[0.190, 0.175]
Angry	0.185	0.003	[0.192, 0.179]
Neutral	0.187	0.003	[0.194, 0.180]
Competition	0.205	0.004	[0.214, 0.197]
Non-competition	0.165	0.003	[0.171, 0.158]
P1 latency [s]			
Happy	0.135	0.003	[0.130, 0.140]
Angry	0.134	0.002	[0.130, 0.139]
Neutral	0.134	0.003	[0.130, 0.139]
Competition	0.143	0.002	[0.148, 0.138]
Non-competition	0.126	0.003	[0.132, 0.121]
EPN amplitude (overall) [μV]			
Happy	1.399	0.337	[2.276, 0.911]
Angry	1.823	0.345	[2.522, 1.124]
Neutral	2.157	0.342	[2.850, 1.465]
Competition	1.824	0.335	[2.502, 1.146]
Non-competition	1.892	0.357	[2.614, 1.169]
EPN amplitude (competition) [μV]			
Happy	1.697	0.351	[2.406, 0.987]
Angry	1.804	0.346	[2.503, 1.104]
Neutral	1.972	0.332	[2.643, 1.302]
EPN amplitude (non-competition) [μV]			
Happy	1.491	0.354	[2.208, 0.774]
Angry	1.842	0.364	[2.579, 1.106]
Neutral	2.342	0.378	[3.105, 1.578]
LPC amplitude [μV]			
Happy	4.838	0.416	[5.680, 3.997]
Angry	5.274	0.413	[6.110, 4.438]
Neutral	4.995	0.397	[5.800, 4.193]
Competition	5.346	0.436	[6.228, 4.463]
Non-competition	4.726	0.382	[5.498, 3.955]

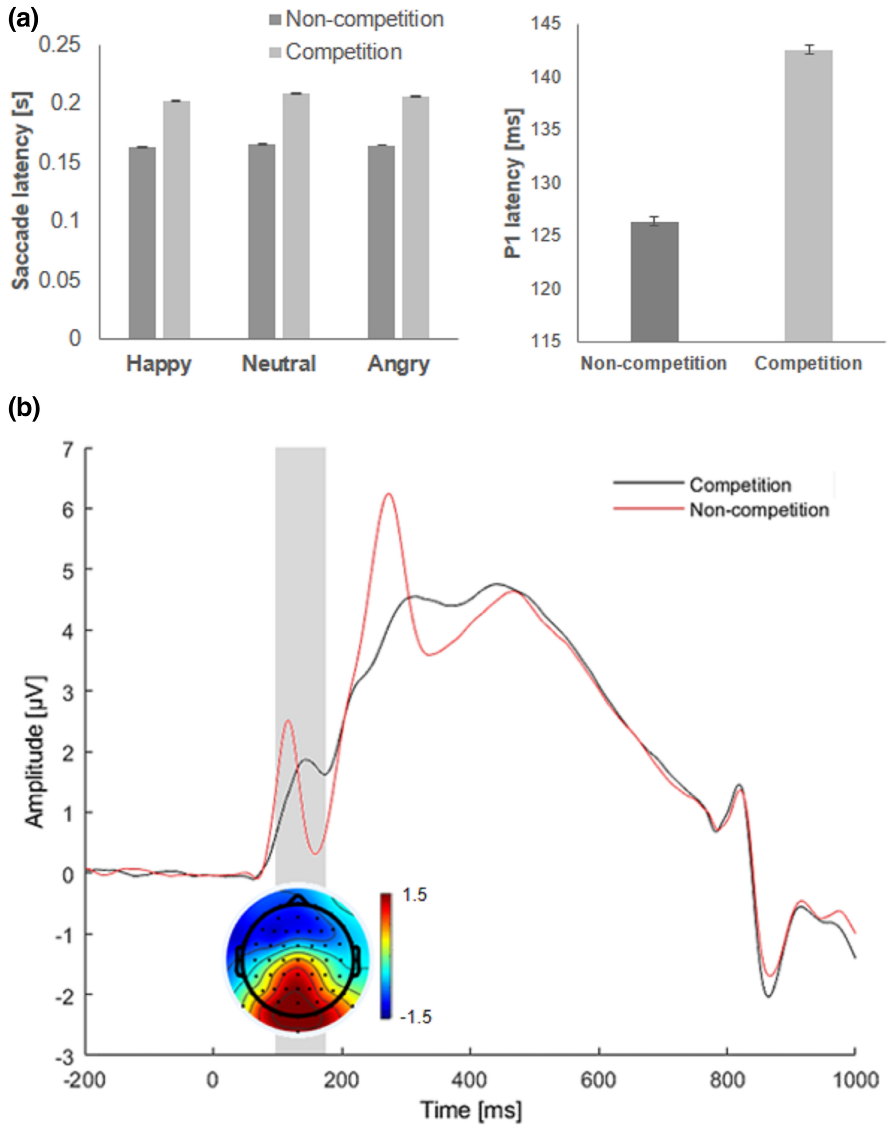

FIGURE 2 (a) Saccade latency (left panel) and P1 latency (right panel) as a function of experimental conditions. Error bars indicate +/− 1SE. (b) Grand average waveforms, including PO7, PO3, O1, PO8, PO4, O2 electrodes, and topographical map of the P1 distribution, averaged within the time window, indicated by the vertical gray box. In the wave plot, non-competition is displayed in red and competition in black

$t(39) = -2.22$, $p = .032$, $d = 0.126$, $BF = 1.528$. In contrast, in the non-competition condition, the EPN was significantly more negative in the happy than neutral face condition, $t(39) = -5.73$, $p < .001$, $d = 0.363$, $BF = 14006.340$, the angry than neutral, $t(39) = -4.32$, $p < .001$, $d = 0212$, $BF = 232.737$, and the happy than angry face condition, $t(39) = -2.56$, $p = .014$, $d = 0.154$, $BF = 3.009$.

3.2.4 | EPN exploratory follow-up analysis

We originally preregistered to investigate the EPN in a time window between 250 and 300 ms after target onset based on previous research. However, visual inspection of Figure 3 suggests that the onset of the EPN may be delayed, in particular in the competition condition, so that a later time window would capture the EPN. To investigate whether this delay accounts for the larger EPN effect for emotional compared to neutral expressions in the non-competition condition, we exploratorily analyzed an additional time window from 300 to 450 ms after target onset using the electrodes and pre-processing steps defined above. In this time window, there was a significant effect of emotional expression, $F(2, 78) = 23.94$, $p < .001$, $\eta^2 = .017$, $BF = 68{,}183$, competition condition, $F(1, 39) = 23.37$, $p < .001$, $\eta^2 = .022$, $BF > 1{,}000{,}000$, as well as a significant interaction effect of emotional expression and competition condition, $F(2, 78) = 4.37$, $p < .001$, $\eta^2 = .001$, $BF = 0.304$. Follow-up t-tests showed that in the competition condition, EPN amplitude did not differ between happy and angry faces, $t(39) = -0.775$, $p = .443$, $d = -0.040$, $BF = 0.226$, but was significantly more negative in the happy than neutral, $t(39) = -3.817$, $p < .001$, $d = -0.228$, $BF = 59.83$, and in the angry than neutral condition, $t(39) = -3.183$, $p = .003$, $d = -0.175$, $BF = 12.06$. In the non-competition condition, EPN amplitude was significantly more negative in the happy than the neutral condition, $t(39) = -6.903$, $p < .001$, $d = -0.412$, $BF = 468370.3$, in the angry than neutral condition, $t(39) = -4.589$, $p < .001$, $d = -0.243$, $BF = 499.93$, and in

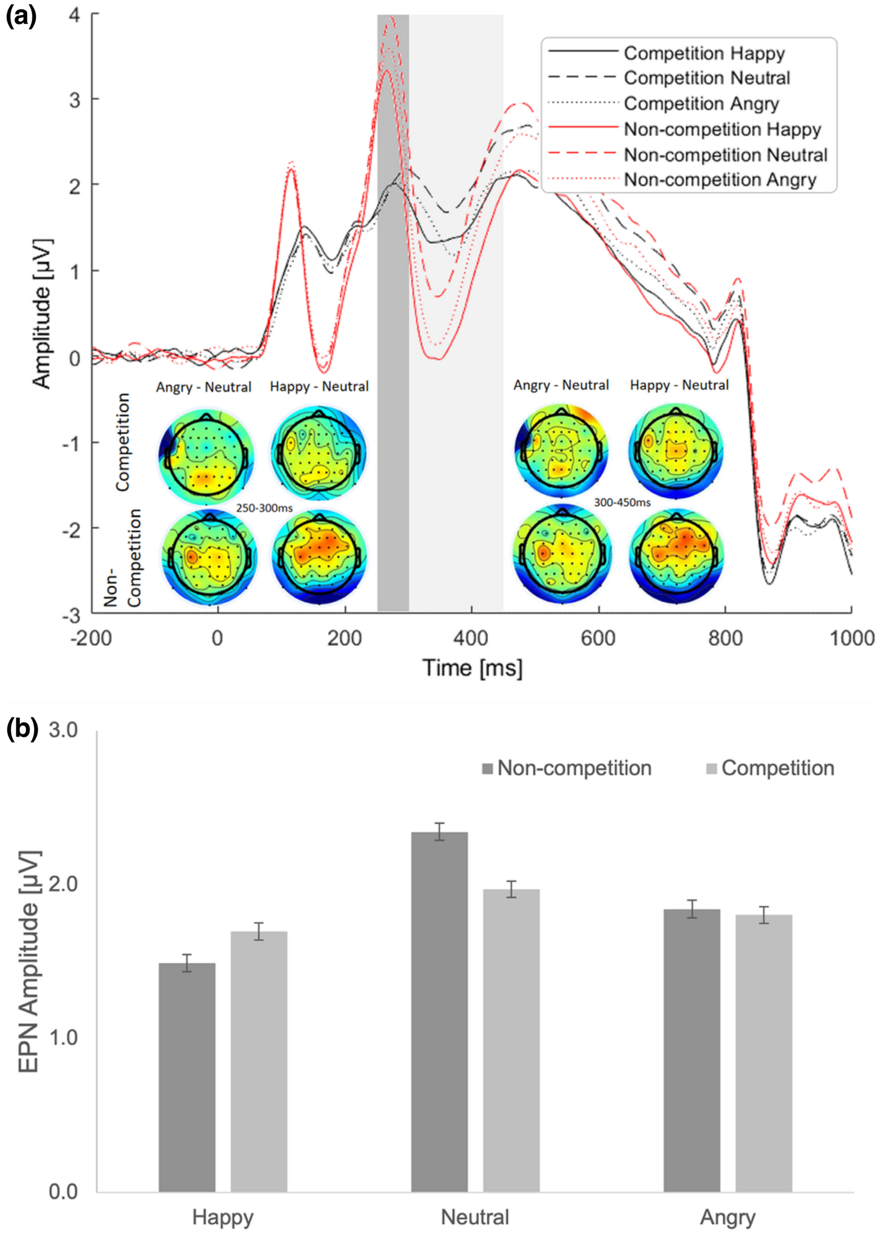

FIGURE 3 (a) EPN amplitude, averaged across electrodes O1, O2, P9, P10, PO7, and PO8, as a function of competition condition and emotional expression and wave and topographical plots depicting the difference between angry and neutral faces and happy and neutral faces in the competition and non-competition condition. EPN amplitude was determined between 250 and 300 ms after target onset (dark gray time window and plots on the left side of the figure). As the wave plot suggests that EPN effect may occur at a later time in the competition condition, the component was additionally extracted in a time window from 300 to 450 ms after target onset (light gray time window and topographical plots on the right side of the figure). (b) Bar plot of mean EPN amplitude in each of the conditions for the original time window. Error bars indicate +/− 1SE

the happy than angry condition, $t(39) = -3.059$, $p = .004$, $d = -0.155$, $BF = 9.00$. Interestingly, the EPN amplitude in this time window was also more negative in the non-competition than in the competition condition for happy, $t(39) = 5.044$, $p < .001$, $d = -0.406$, $BF = 1856.84$, angry, $t(39) = 4.500$, $p < .001$, $d = -0.271$, $BF = 388.85$, and neutral faces, $t(39) = 3.049$, $p = .004$, $d = -0.224$, $BF = 8.78$. Therefore, we found similar results, albeit with a stronger effect of emotional expression while analyzing the EPN in the time window between 300 and 450 ms compared to the pre-registered time window between 250 and 300 ms.

3.2.5 | LPC amplitudes

There was a significant effect of emotional expression, $F(2, 78) = 12.52$, $p < .001$, $\eta^2 = .005$, $BF = 21.946$, and of competition condition, $F(1, 39) = 27.62$, $p < .001$, $\eta^2 = .014$, $BF > 1.000.000$, but no significant interaction, $F(2, 78) = 0.85$, $p = .431$, $\eta^2 < .001$, $BF = 0.139$ (Figure 4). Follow up t-tests showed that LPC amplitude was significantly smaller for happy than angry faces, $t(39) = -5.06$, $p < .001$, $d = 0.166$, $BF = 1924.589$, and for neutral than angry faces, $t(39) = -3.20$, $p = .003$, $d = 0.107$, $BF = 12.457$, but did not differ between happy and neutral faces, $t(39) = -1.72$, $p = .093$, $d = 0.060$, $BF = 0.656$.

3.2.6 | Exploratory correlation analysis of P1 latency and saccade latency

To relate P1 and saccade latency, a Pearson's product–moment correlation analysis was conducted using the cor function of the ggpubr library in R. For this purpose, a long

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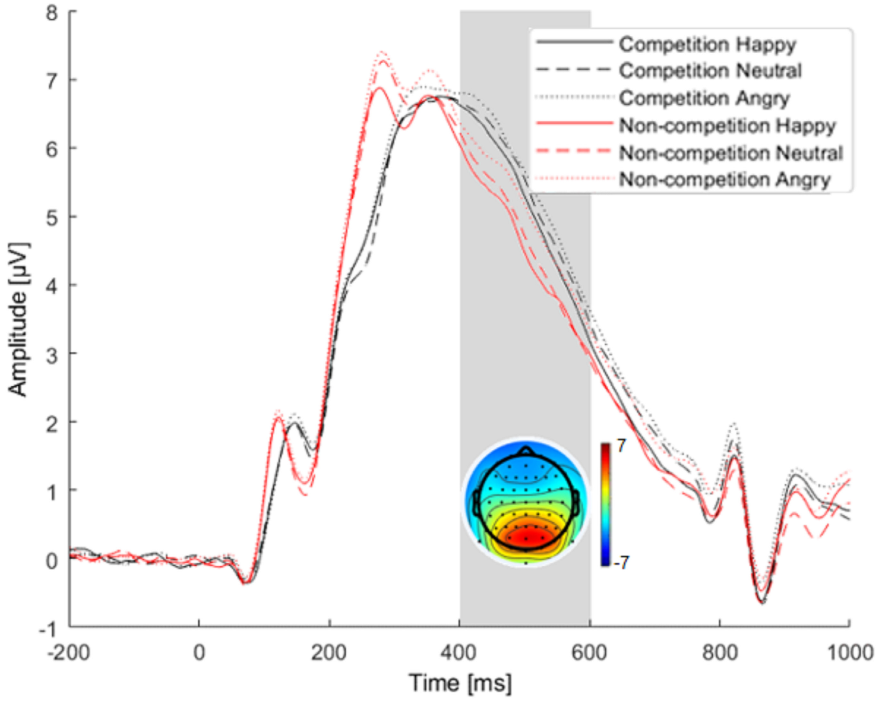

FIGURE 4 Wave and topographical plot of the LPC measured between 400 and 600 ms after stimulus onset in an occipito-parietal electrode cluster including Pz, POz, PO3, and PO4

data format with saccade latency and P1 latency averaged across each respective condition was used (note that it was not possible to correlate values for each trial, as EEG data needs to be averaged across several trials to achieve sufficient data quality for P1 analysis). P1 latency significantly correlated with saccade latency, $r(238) = .329$, $t = 5.374$, $p < .001$.

4 | DISCUSSION

The current study aimed to investigate the saccadic and neural mechanisms underlying overt attention shifts to emotional and neutral faces, with two targets competing for attention compared to when there was no competition.

4.1 | Summary of results

Attention shifts were significantly faster in the non-competition condition than in the competition condition, as indicated by shorter P1 latencies and shorter eye-movement latencies, while P1 amplitude did not differ between competition conditions, in line with previous literature (Atkinson et al., 1988, 1992; Atkinson & Braddick, 1985, 2012; Hood & Atkinson, 1993; Kulke et al., 2020). Also in line with previous research (Kulke, 2019), emotional expression of the peripherally presented target faces had negligible effects on the speed of attention shifts, with no effects of emotional expression on P1 latency, although eye-movements were faster to happy than to neutral and angry faces. Clear main effects of emotional expression were evident at the EPN, with significantly larger (i.e., more negative) amplitudes in response to both happy and angry compared to neutral faces, which is in line with hypotheses and with the previous literature (Kulke, 2019; Kulke et al., 2021; Recio et al., 2011; Rellecke et al., 2012). LPC amplitudes were larger in competition than in non-competition and larger toward angry than happy and neutral faces.

The novel approach of the current study further allowed to investigate potential interactions between competition and emotion-drawn attention. Interestingly, the emotional expression effect on the EPN significantly interacted with competition/non-competition condition, showing significantly smaller emotional expression effects when a central target competed for attention. An exploratory follow-up analysis indicated the EPN and the valence effects to occur later in the competition than the non-competition condition, i.e., after 300 ms. The LPC was significantly larger in competition than non-competition conditions and, unexpectedly, larger in response to angry compared to neutral and happy faces. This emotional expression effect on the LPC contradicts the hypothesis built on Kulke (2019) but is in line with many studies showing enlarged LPC amplitudes to emotional faces presented centrally (Recio et al., 2011; Rellecke et al., 2012; Schacht & Sommer, 2009). Individual differences in the observed effects were negligible, as reported in Supplement B.

4.2 | Early effects of competition

The observed differences between *competition and non-competition conditions* indicate that competition between two targets clearly affects attention shifts on an early level, as it affects both fast eye-movements as well as very early ERPs which occur before for saccade onset (Atkinson et al., 1992; Hood & Atkinson, 1993; Kulke et al., 2015, 2016b, 2020). During competition, a disengagement from the central stimulus is required in addition to the attention shift to the new target. This disengagement reliably requires additional time. As already the P1 is affected by the disengagement, this suggests that neural responses are decelerated due to competing targets. As the P1 has been suggested to stem from visual cortical areas, which are highly connected with the Superior Colliculus (Collins et al., 2005; Schiller & Tehovnik, 2005), which is involved in saccades (Schiller & Stryker, 1972; Wurtz & Goldberg, 1972), there may be a relation between P1 responses and shifts of attention, as previously suggested for covert (e.g., Gonzalez et al., 1994; Luck et al., 1990) and overt attention shifts (Kulke et al., 2020). During this process, the latency of the P1 seems to play a more crucial role than its amplitude. In the previous literature, some studies found amplitude effects while others did not (for a recent review, see Schindler & Bublatzky, 2020), so the current study adds to the idea that P1 latency is a more crucial factor during overt attention shifts than its amplitude (Kulke et al., 2020). It should be noted that previous research showed that the P1 is influenced in shape and amplitude both by the offset of the central stimulus that a participant disengages from and by the peripheral target (Kulke et al., 2020); therefore, the overall visual layout of the display may contribute to the observed effects (Gupta et al., 2019; Luck et al., 1990, 1993; Wirz & Schwabe, 2020), though the effects are comparable for fractional area latency and peak latency measures (Kulke et al., 2020).

4.3 | Early effects of emotional content

4.3.1 | Emotion effects on the P1

While the *P1 latency* was impacted by competition versus non-competition, it was unaffected by *emotional expression*, as confirmed by Bayesian statistics. The absence of these effects suggests that cortical responses prior to reflexive saccade onsets might not be modulated by emotional expression, which is in line with a previous study on reflexive overt attention shifts (Kulke, 2019).

4.3.2 | Emotion effects on saccade latency

The current study's finding of faster *saccades* to happy than toward neutral faces was unexpected, based on a previous study investigating fast and reflexive shifts (Kulke, 2019). Emotion effects on *eye-movements* were generally mixed in the previous literature (Bannerman et al., 2012; Kissler & Keil, 2008; Nummenmaa et al., 2006). However, a recent study investigating slower controlled overt attention shifts found effects of emotional expression (Kulke et al., 2021), suggesting that effects of emotional expressions on saccades may be modulated by task demands. They do not seem to occur for simple reflexive shifts during a paradigm in which eye-movements are required completely independent of the displayed stimulus. However, as soon as the shift varies with the conditions (e.g., if participants are only required to look under certain conditions), emotion effects start to emerge, for example, if a go/no-go task is introduced (Kulke et al., 2021) or if shifts differ depending on competition and non-competition conditions, as in the current task. In line with previous emotional attention accounts, this may suggest that resources need to be allocated to emotional stimuli in order for eye-movements to be influenced by their valence in the current competition / non-competition design (Pessoa & Ungerleider, 2005). Saccade effects may also be difficult to detect, possibly because effects of emotional expression are less consistent across participants, as individual differences have previously been observed (Bradley et al., 2000; Mogg et al., 2004; Wieser et al., 2009, 2018). In the current study, the effects were small and may disappear if multiple comparisons were corrected for, rather than preregistering analyses without correction. As disengagement is required during countless shifts in everyday life, it may be so crucial during attention shifts that it consistently shows across participants, as demonstrated from infancy until late adulthood and in typical and clinical populations (Atkinson & Braddick, 2012; Atkinson et al., 1988, 1992; Butcher et al., 2000; Colombo, 2001; Elsabbagh et al., 2009, 2013; e.g., Farroni et al., 1999; Hood & Atkinson, 1993; Johnson et al., 1991; Kulke et al., 2016a, 2016b, 2020; Matsuzawa & Shimojo, 1997). However, being able to shift attention at all is a crucial requirement that needs to be met before one can differentially shift toward different emotional expressions. It may therefore depend on individual differences and familiarity with certain emotional expressions whether or not very basic attention shifts are influenced by emotional expressions (see the discussion of individual differences in Supplement B).

4.3.3 | Late effects

Clearer effects of both competition and emotional expression were observed on later responses such as the LPC and EPN.

Larger amplitudes of the LPC occurred in the competition than in the non-competition condition and in response to angry faces. The LPC may be related to task difficulty of attention shifts in the current study and attention shifts are more difficult under competition. In line with this interpretation, participants could also find it more difficult to shift toward angry faces. This may be due to a subliminal inhibition to shift to angry faces which needs to be overcome, leading to larger LPC amplitudes to angry faces in the current paradigm. As participants with higher social anxiety shifted faster toward angry than toward neutral faces (Supplement B), they may find it less difficult to shift attention to angry faces, as they are used to over-processing emotional information. An alternative explanation may be that additional late-processing resources are oriented toward angry faces and that the enhanced LPC reflects investment of additional late-processing resources in this case. Although effects of emotional expression on the LPC are in line with many previous studies (Hinojosa et al., 2010; Recio et al., 2011; Rellecke et al., 2012; Schacht & Sommer, 2009), studies on overt attention shifts to emotional faces, similar to the present study, failed to demonstrate these effects (Kulke, 2019; Kulke et al., 2021). As the LPC has been related to cognitive load of tasks, as well as emotional content, possibly, task difficulty was more salient in the current task including competition and non-competition conditions, compared to paradigms that did not vary these conditions.

Effects of emotional expressions on the EPN were in line with many previous studies, confirming the sensitivity of this component to emotional expressions (Rellecke et al., 2011, 2012; Schacht & Sommer, 2009; Schindler & Bublatzky, 2020; Schupp et al., 2004). As a novel and unexpected finding, the current study discovered that EPN modulations were less pronounced when another stimulus competed for attention and occurred later than in non-competition conditions and than in previous research. To our knowledge, the current study is the first to demonstrate such an effect during overt attention shifts. It is possible that, when several objects are competing for attention, the processing of their emotional content/expression is reduced. The response to the emotional content of the peripheral target furthermore was delayed, possibly due to the ongoing processing of the central stimulus. Put differently, emotional expressions are not processed as reliably when another object preoccupies a person's attention. This finding from our overt attention shift task is in line with the view that emotional expressions are only processed if sufficient attentional resources are available (Pessoa & Ungerleider, 2005), while contrasting the view that emotional attention is automatic (e.g., Pourtois et al., 2004). As overt attention shifts frequently occur in everyday life, this novel finding indicates that distractions, which typically occur in crowded natural visual scenes, can suppress noticing the emotions that others express. A follow-up analysis further showed that EPN effects were smaller and occurred later in the competition than in the non-competition condition. Hence, disengagement of attention from the central stimulus might be required before emotional expression of peripheral stimuli can be processed, leading to delayed emotion processing under competition. This fits with the Perceptual Load Theory suggesting that processing of perceptual details, such as emotional expressions is impaired when objects are competing for attention (Lavie, 1995). It furthermore supports the theory by Pessoa and Ungerleider (2005) that suggests that emotional salience is only automatically processed if sufficient processing capacity is available, which may not be the case when several objects are competing for attention.

As a cautionary note, it should be considered that eye-movements may overlap with EPN and LPC time windows extracted in the current study. However, the co-registered eye-tracking findings demonstrate that most eye-movements occurred earlier than the extracted time windows. Although artifacts were removed using ICA, this procedure involved manual coding and is, therefore, subjective. Furthermore, eye-movements lead to a change in the visual scene. This change occurs earlier in non-competition conditions, which may lead to larger emotion effects on the EPN, because it is more likely that emotional expression was already foveally processed in non-competition conditions. Such differences cannot be avoided if natural differences in overt attention shifts are studied. Yet, we believe that natural shifts of attention are highly important to consider for translational implications and that looking into overt shifts of attention is one step toward studying more natural shifts as participants are no longer instructed to inhibit natural eye-movements (Kulke & Pasqualette, 2022). In everyday life, an abundance of different objects is constantly competing for our attention and for fixation. The current study demonstrates that salient distractors, such as faces that are centrally fixated can distract from processing emotional expressions of peripheral objects and even attenuate neural responses toward them.

In summary, competition between two targets can decelerate eye-movements and the P1 response, but also has significant effects on later neural processing of peripheral stimuli, attenuating responses to their emotional expression. Therefore, competition not only affects responses to the physical presence of a stimulus but also to emotional salience of targets.

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AUTHOR CONTRIBUTIONS

Louisa Kulke: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; supervision; visualization; writing – original draft; writing – review and editing. **Lena Brümmer:** Conceptualization; data curation; formal analysis; investigation; methodology; project administration; visualization; writing – review and editing. **Arezoo Pooresmaeili:** Conceptualization; funding acquisition; methodology; supervision; writing – review and editing. **Annekathrin Schacht:** Conceptualization; funding acquisition; methodology; resources; supervision; writing – review and editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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