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TASK IRRELEVANT EMOTION EFFECTS ON TOP-DOWN ATTENTION: AN ERP STUDY

Master thesis

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Running head: TASK IRRELEVANT EMOTION AND TOP-DOWN ATTENTION

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Abstract

It has been shown that emotional stimuli can attract attention away from the task at hand, resulting in slowed reaction times. However, there are still discrepancies regarding the exact conditions and temporal dynamics under which this preferential mechanism operates. To investigate the matter further, an ERP experiment using peripherally presented fearful and neutral faces was conducted. Emotion was kept task irrelevant in all conditions by having participants solve a simple gender discrimination task on faces presented at precued locations. Behavioural results indicated that fearful faces were responded to slower and with decreased accuracy rates. No modulatory effects of emotion on ERPs sensitive to the allocation of spatial attention were found. Nevertheless, strong emotion effects were observed in the form of a late positive component (LPP), suggesting that affective and top-down attention work independently and that emotion only gains precedence after attentional resources are left over from processing task relevant information, prolonging disengagement from emotional faces and thereby affecting response times.

Keywords: affective attention; top-down attention; event-related potential

Kokkuvõte

Varasemad uuringud on leidnud, et emotsionaalsed stiimulid võivad endale tõmmata tahtmatut tähelepanu parasjagu lahendatava ülesande arvelt, põhjustades seeläbi aeglasemaid reaktsiooniaegu. Siiski pole veel päris selge, millistes tingimustes ja ajavahemikes selline eelistöötlemine aset leiab. Sellele küsimusele vastust otsides kavandati ERP eksperiment, mille käigus esitati osalejatele perifeerselt emotsionaalse või neutraalse ilmega nägusid. Emotsioon oli selles kontekstis ebaoluline, kuna ülesanne dikteeris, et vastuseid tuleb anda osutatud näo soo kohta. Käitumisandmed näitasid, et hirmunägudele vastati aeglasemalt ja rohkemaid vigu tehes. Emotsioon aga ruumitähelepanule tundlikke ERP-e ei moduleerinud. Siiski olid emotsiooni efektid selgelt jälgitavad hilise positiivse komponendi näol (LPP), viidates sellele, et afektiivne tahtmatu tähelepanu ja tahtlik tähelepanu töötavad teineteisest sõltumatult. Võimalik, et emotsioon hakkab mõju avaldama alles siis, kui ülesande sooritamiseks vajaminev informatsioon on juba piisaval määral töödeldud ja tähelepanulisi ressursse on sellest tegevusest üle jäänud. Emotsiooni segav mõju näib seega tulenevat aeganõudvamast tähelepanu lahtihaakimisest emotsionaalsetelt nägudelt, mis omakorda pikendab reaktsiooniaegu.

Võtmesõnad: tahtlik tähelepanu, tahtmatu tähelepanu, emotsioon, ERP

Töö pealkiri eesti keeles: „Tahtmatu afektiivse tähelepanu mõju tahtlikule tähelepanule: ERP uurimus“

Emotion and attention

Emotional stimuli are widely considered to be subject to prioritised processing due to their evolutionarily significant role in human survival. Threat related stimuli in particular need to capture awareness and be identified rapidly in order to avoid potentially dangerous situations or to deal with them promptly (activation of the fight or flight system). Studies have shown that fear related targets are detected faster among fear-irrelevant distractors than vice versa (e.g. Reinders, Den Boer, & Büchel, 2005; Öhman, Flykt, & Esteves, 2001). On the other hand, an automatic capture of attention independent of top-down selective mechanisms can bear repercussions on task performance and be disadvantageous in everyday living. In experiments where emotion is task irrelevant, the emotional valence of a stimulus can compromise task performance by slowing reaction times. Some experiments using variations of the Stroop task have shown that naming the colour of a word takes longer when the word has an emotional meaning (e.g. Richards & Blanchette, 2004; Gootjes, Coppens, Zwaan, Franken, & Van Strien, 2011). While the overall tendency of emotionally salient information to be processed in a prioritised manner has been well documented, it is still far from clear how affect-specific attention mechanisms interact and compete with top-down attention.

There are still discrepancies in studies trying to understand whether or not top-down attention is required for emotion perception and there is empirical evidence to support both sides (for reviews see Pessoa, Pereira, & Oliveira, 2010; Pourtois, Schettino, & Vuilleumier, 2013). An fMRI study by Vuilleumier, Armony, Driver, and Dolan (2001) has gathered evidence to support the notion that emotional processing is preattentive and obligatory at least to some degree. Using an experimental paradigm where the subjects maintained central fixation while being asked to compare either two faces (fearful or neutral) or two houses presented horizontally and vertically on the screen. The focus of attention was shifted to the left and right of fixation while ignoring the top and bottom stimuli, or the other way around. Responses in the left amygdala evoked by fearful compared to neutral faces were equivalent whether or not the faces were attended, suggesting that top-down attention was not needed to process the emotional valence of said stimuli. Reaction times were also slower when the unattended faces were fearful compared to when they were neutral, confirming that emotional faces captured attentional resources away from the processing of houses.

Conflicting evidence was found in another fMRI study by Pessoa, McKenna, Gutierrez, and Ungerleider (2002). Activations in the amygdala and other brain regions sensitive to emotional content were measured while subjects maintained central fixation. A face (either neutral or emotional) was presented at fixation with bars in the left and right periphery. On attended trials subjects had to make judgements on the gender of the centrally presented face. Meanwhile, on unattended trials they had to make high demand judgements on the orientation of the peripherally presented bars. Results contradicted those found by Vuilleumier et al. (2001) in that all brain regions that responded differentially to emotional content did so only when the face was attended and not when attentional resources were consumed by the peripherally presented task. No difference in reaction times as a function of the emotional valence of the unattended face was observed. The authors concluded that the demanding task had exhausted processing resources leaving none available for task irrelevant emotion.

Despite the fact that activity from the amygdala cannot be directly recorded with the electroencephalograph (EEG), its modulatory effects on neocortical visual areas should still be observable through event related potentials (Sabatinelli, Lang, Keil, & Bradley, 2007). The contradictory findings have in fact been replicated using ERPs as well. For instance, Schupp, Junghöfer, Weike, and Hamm (2003) have demonstrated that emotional modulations of early ERPs remain independent of top-down attention engagement while performing an explicit non-emotional attention task. In contrast, an ERP study (Holmes, Vuilleumier, & Eimer, 2003) using a similar experimental design to that of Vuilleumier et al. (2001) discovered that all emotion expression effects that were observed in conditions where emotional faces were attended and task relevant were completely eliminated when the faces were presented at unattended locations. But again, top-down attention was directed away from faces and engaged in a demanding perceptual discrimination task, much like in the experiment by Pessoa and colleagues (Pessoa, McKenna et al., 2002).

Existing literature therefore suggests that affective attention can under certain conditions operate without the presence of top-down attention, unless engaged in a high-load demanding task that is located away from emotional features. The next important step is to understand the mechanisms underlying the performance of task irrelevant affective attention in conditions where it does affect visual processing and to further clarify the temporal dynamics of those effects. In this context, the present ERP study was designed with special emphasis on the modulatory effects of subcortical affective attention on neocortical top-down attention in conditions where the emotional features of stimuli are always task irrelevant yet not always at task irrelevant locations, allowing for a comparison of the effects of emotion on spatial and feature-based attention.

Current study goals

Inspired by the examples of the introduced experiments, as well as several others in this line of studies (for a review see Palermo & Rhodes, 2007), the current study was designed using peripherally presented neutral and fearful face stimuli. Since there is plenty of evidence to suggest that when the emotional stimulus is presented at a task irrelevant location, attending to a demanding non-emotional task will eliminate all emotion effects (Holmes et al. 2003; Pessoa, McKenna et al., 2002; Pessoa, Kastner, & Ungerleider, 2002), it was instead decided to explore the effects of task irrelevant emotional features when attending to the non-emotional features of said stimulus. Emotion was kept task irrelevant in all conditions by having subjects identify the gender of the attended faces. A gender discrimination task is not very demanding and should therefore allow for attentional resources to be left over from the task at hand. As faces are still attended at all times (as opposed to houses, lines, or other objects), features of facial expression were expected to be processed at least to some degree. The different conditions allowed for a comparison between the effects of task irrelevant emotional features when at attended versus unattended locations, with the intent to analyse in detail at which temporal stages of processing affective attention interacts with top-down attention, if at all.

We anticipated to see emotion effects on a behavioural level and possible emotion modulations of some ERPs sensitive to the allocation of top-down spatial attention. For example, increased early positive and negative amplitudes (P1, N1) in response to emotional stimuli have previously been reported (Hajcak, Weinberg, MacNamara, & Foti, 2010; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005). Late effects of emotion are most frequently reported as a slow positive wave that is enhanced after the presentation of pleasant and unpleasant compared to neutral pictures. This late positive potential (LPP) is observed to last the full duration of stimulus presentation, even persisting into the period following emotional picture offset (Hajcak & Olvet, 2008). The LPP is considered to measure sustained attention to emotional content (Hajcak et al. 2010) and has been shown to be modulated by task relevance and top-down attention to some extent (Foti & Hajcak, 2008; Valdés-Conroy, Aguado, Fernández-Cahill, Romero-Ferreiro, & Diéguez-Risco, 2014).

Emotion modulations in the early visual components that are usually affected by top-down attention would provide evidence in favour of the idea that a rapid and automatic capture of attention by emotionally relevant stimuli occurs at a very early stage of processing and, when emotions are task-irrelevant, becomes suppressed later by top-down attention in favour of task relevant goals. On the other hand, if emotion only modulates late attentional components, this might suggest that the emotional distractor effects often reported in behavioural results are not so much a result of the preattentive processing of emotion, but rather that emotion can interfere with top-down attention after the primary task has been completed, if there are any attentional resources left over.

As we were also curious whether emotion can have modulatory effects on preparatory attention prior to stimulus onset, an emotional cue was added to the spatial cue on half of the trials. A neutral stimulus (in this case a coloured circle) when paired in temporal contiguity with an emotional stimulus, acquires the ability to predict future occurrences of the emotional event (Dolan, 2002). Therefore a valid cue correctly predicting the emotional valence of upcoming stimuli is expected to have effects comparable to those of actual emotional stimuli through associative learning. The index of preparatory attention is considered to be the contingent negative variation (CNV) component which is a slowly changing, negative-going potential that is dependent on the perception of contingency between warning and response stimuli (Fernandez, 2013). The CNV has two phases – an early wave related to the evaluation of a warning signal (cue) and a later wave related to the preparation of target perception and motor response (Padilla, Wood, Hale, & Knight, 2006).

In summary, the general goal of this study was to explore to what extent and at what latencies task irrelevant emotion affects stimulus processing and modulates top-down attention on a behavioural and neocortical level, thereby helping to further contribute to the already impressive body of work dedicated towards a better understanding of the preattentive nature of emotion.

Method

Participants

Forty-six people from the age of 19 to 42 participated in the experiment after giving informed consent. Thirty-three of the subjects were female and 13 were male. Most of the participants were right-handed with the exception of two people. All participants had normal or corrected-to-normal vision. Altogether 13 participants were excluded during the artefact removal phase as a result of excessive eye movements, leaving a total of 33 subjects (24 female and 9 male) in the final sample (age M = 21.84; SD = 2.16).

Stimuli

Coloured photos of eight different persons (four male and four female) depicting fearful and neutral expressions were selected from the Radbound Faces Database (Langner et al., 2010). The selection of stimuli was made based on the scores depicting inter-rater agreement with intended expression, clarity of expression and genuineness of expression of each photo which were provided with the database. Faces where both fearful and neutral images had an agreement level of over 90% were retained for inclusion, leaving four males and nine females that met the criterion. Four females were chosen from that selection based on clarity and genuineness scores which were most similar to those of the selected males. To ensure uniformity of stimuli, all images in the final database were resized to fit an elliptical shape of uniform size on a grey background, removing the hairline and leaving only the facial area visible (Figure 1).

Figure 1. Example of a fearful female and a neutral male stimulus

Procedure

Experiments were conducted in a dimly lit sound-attenuated chamber. The subject was seated 100 cm from a computer screen with height adjusted to eye level. Each trial began with a black fixation cross presented at the centre of the dark grey screen for approximately 1 s (with 17% variability), followed by an attentional precue in the form of a black arrow pointing either to the right or left visual field, also presented centrally. The cue remained on screen for 330 ms before turning back into a fixation cross. Subjects were instructed to maintain their gaze at the centre of the screen at all times. Two face stimuli appeared on either side of the screen 1 s after the onset of the attentional cue. All stimuli were presented on a grey background (RGB values: 85, 85, 85) with a size of 7° of visual angle. A male face was always paired with a female face, and vice versa. The two faces could form a combination of two fearful, two neutral, or one fearful and one neutral face. All combinations of stimuli appeared an equal number of times within the span of the experiment. Each stimulus pair stayed on the screen for 330 ms. The interval between the offset of the stimuli and the beginning of the next trial was 1 second.

Simultaneously with the centrally presented spatial attention cues, peripheral emotional cues appeared on both sides of the arrow, in the same screen location where the face stimuli would be presented. Emotional cues consisted of colourful or grey circles, providing additional information about the emotional valence of the stimuli in 50% of the trials. A green circle signified a neutral face, a red circle an emotional face and a light grey circle meant that no cue information about the emotion of the stimuli would be presented on this trial. The subjects were informed of these cues, but asked to pay little attention to them, thus maintaining an aspect of task irrelevancy of the pre-stimulus emotional condition as well.

Subjects were instructed to direct their attention, but not their gaze, to the stimulus indicated by the attentional cue and to discriminate the gender of the attended face by pressing one of two mouse buttons with their thumb. The computer mouse was held in the right hand of the subject, in a horizontal position, with the thumb resting between the two buttons to avoid any bias in reaction times. Subjects received automatic feedback if they provided a false answer, in order to assure that they had not reversed the assigned mouse buttons by accident. While instructing the participants, special emphasis was placed on the need not to divert gaze from the centre of the screen towards the stimuli. The display duration of the stimuli was also kept brief to minimise saccades. Nevertheless, additional measures to ensure that this instruction was properly followed were taken during artefact removal phase.

The experiment consisted of three experimental blocks and a practise block of 20 trials at the beginning. There was a short break after each experimental block. Each unique stimulus pair was presented four times making a total of 512 trials. All stimuli were presented in randomised order.

EEG Recording

Electroencephalogram (EEG) was recorded with the BioSemi Active Two system. 32 electrodes were mounted in a whole-head electrode cap on the basis of the 10-20 system and two electrodes were placed on the left and right mastoids. The electrooculogram (EOG) generated from blinks and eye movements was recorded from four facial electrodes: the horizontal EOG was recorded bipolarly from the outer canthi of both eyes, and the vertical EOG was recorded from electrodes placed approximately 1 cm above and below the left eye. The amplifier bandpass was 0.16 to 100 Hz and the digitisation rate 512 Hz. No additional filters were applied to the averaged data.

EEG processing

EEG data was preprocessed using Independent Component Analysis (ICA) for ocular artefact correction. For optimal ICA solutions a separate copy of the data was used for each participant. The ICA training data sets were high-pass filtered at 1 Hz and segmented from fixation (1 s before cue) to 2 s after stimulus onset, as well as cleaned of channels with improbable data distribution (threshold 5 SD) and of segments with excessive muscle noise (15-30 Hz). Infomax ICA algorithm was applied to each of the data sets with EEGLAB default settings. Independent components with features of eye-blinks and horizontal eye movements were identified visually for each participant and removed from the original continuous data.

The ICA-pruned continuous data was then epoched into 2600 ms periods, starting 1000 ms prior to cue onset and ending 600 ms after stimulus onset. For artefact removal, epoched data was subjected to three separate stages of data clean-up. Firstly, to remove trials where eyeblinks occurred during a critical timeframe from cue onset (0 ms) until stimulus offset (1330 ms) and thus might have influenced subjects' processing of essential information (such as cue direction or stimulus properties), trials where voltage within the time course of the independent component (IC) identified as a reflection of blinks exceeded ±35 μV were removed. In a few exceptional cases a stricter criterion (±30 μV or ±25 μV) was deemed more fitting by visual inspection and therefore applied. Secondly, to remove trials with horizontal eye-movements, the time-course of IC corresponding to horizontal eye-movements was analysed for fast voltage shifts typical of saccades. One of three cut-off criteria were used based on visual inspection: the standard deviation of the component by 1, 1.5, or 2 times. Thirdly, to remove muscle activity and other artefacts, a threshold and spectral method with the threshold rejection limit of ±150 μV per baseline, and spectral rejection limit of ±35 μV (in the range 15-30 Hz) was used. If one channel (with eye channels omitted from analysis) was responsible for over 2% of data removal, the channel was excluded and the algorithm applied to the data again. If these measures resulted in the removal of over 50% of trials in any of the experimental conditions, the subject was excluded from analysis.

Data analysis

In order to analyse the possible effects of emotion on spatial attention, components reflecting a significant difference in the attentional condition had first to be identified. The method of mass univariate analysis was chosen to help avoid problematics associated with “double dipping” (Kriegeskorte, Simmons, Bellgowan, & Baker, 2009). Following the assumption that visual information presented to the left or right of the point of fixation will be projected directly to the contralateral hemisphere (Fernandez, 2013), the EEG data was collapsed over homologous electrodes in the hemisphere contralateral to the image location and averaged separately for the different combinations of conditions pertaining to each individual stimulus. This strategy was adopted to ascertain that the ERPs selected were genuine markers of spatially selective attentional processing rather than a result of any type of asymmetric hemispheric activation. Since emotion effects were of interest, only data from the emotional cue condition was analysed in the time frame before stimulus onset (0-1000 ms). Time frames where the difference between the two spatial conditions (attended/unattended) appeared significant ($p = 0.01$, uncorrected) were selected for further analysis (Figure 2). Scalp maps were used to find electrodes where the effect was largest. Post cue mean N1 amplitudes were averaged between 150-200 ms at the occipital electrodes O1/2. A preparatory slow negative wave was measured from the C3/4 electrodes in two time frames due to apparent differences in scalp map distributions – a more broadly distributed early negativity between 300-500 ms and a later component from 700-1000 ms. Post stimulus P1 and N1 components were averaged over the time frames 80-130 ms and 150-200 ms at electrodes P7/8; a sustained posterior negativity from stimulus offset (330-600 ms) was also averaged from P7/8 where the effect appeared most prominent.

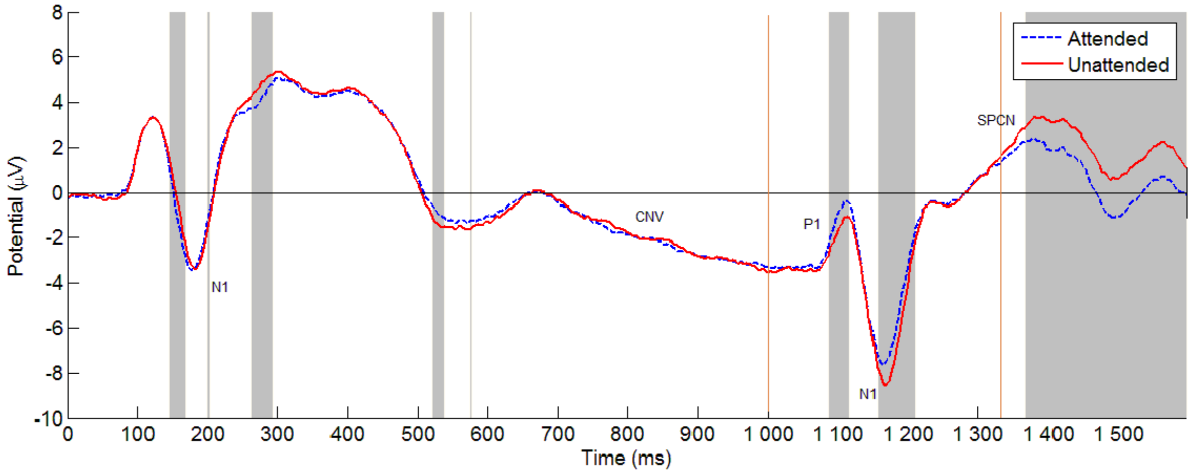

Figure 2. Mass univariate analysis of the spatial attention effect. Contra- and ipsilateral waveforms averaged at electrodes P7/8 over the full epoch from cue onset to 600 ms post stimulus onset with components selected for analysis marked on the graph. Shaded areas denote significant differences (p < .01, uncorrected), yellow lines at 1000 ms and 1330 ms signify stimulus onset and offset.

To explore ERPs that could be sensitive to emotion but not attention, a separate mass univariate analysis was conducted with regard to the emotion condition (Figure 3). While the effects of spatial attention were assumed to occur contralaterally to the attended stimulus, no assumptions were made for the emotional effects which may or may not exhibit a lateralised pattern. The data were not collapsed over hemispheres for this analysis. Again, only data from the emotional cue condition was analysed before stimulus onset. The emotion effects post cue appeared significant over the N1 time frame (140-200 ms) at posterior electrodes, as well as a midfrontal negativity between 280-350 ms which was not present at the spatial condition mass univariate analysis and was therefore retained for further inspection. The significant emotion effects post stimulus were present in the form of a slow positive wave starting at approximately 250 ms post stimulus and appeared confined to central electrodes. The data was first averaged over two separate segments to describe processing that occurred during stimulus presentation (220-330 ms) and processing related to sustaining relevant information after stimulus offset (330-600 ms). However, as the scalp map did not indicate any change in activity during these time frames nor were there any major differences in the repeated measures ANOVA results, the two segments were combined for clarity and analysed as one LPP component from the Pz electrode between 250-600 ms post stimulus onset.

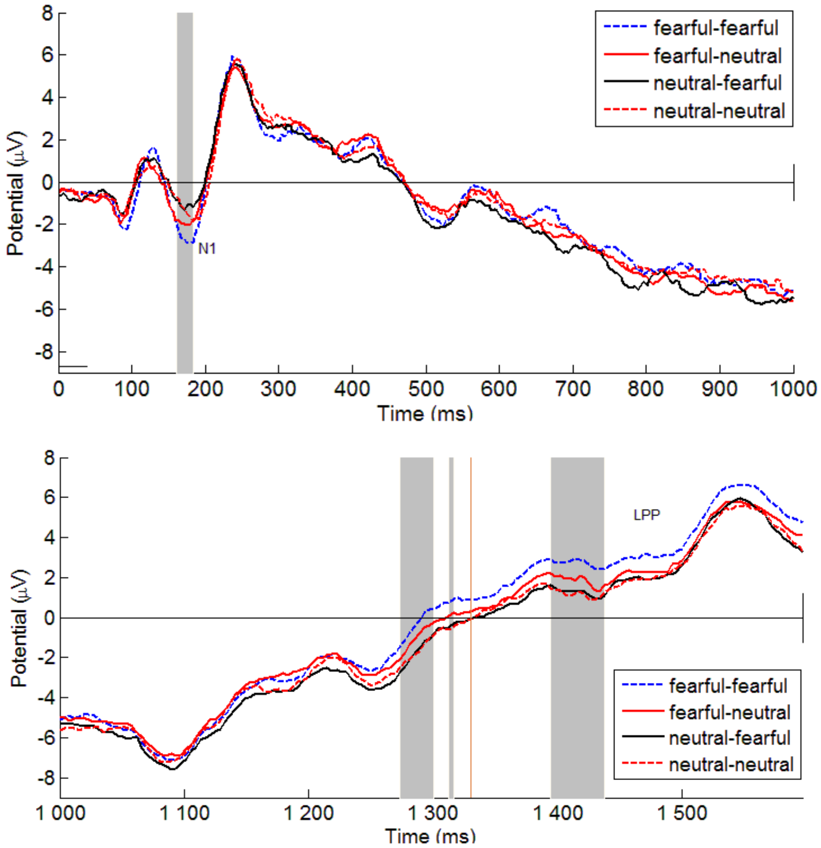

Figure 3. Mass univariate analyses averaged over the central posterior electrode Pz separately for the pre stimulus time frame (0-1000 ms) using data only from the emotional cue condition (top) and for the post stimulus time frame (1000-1600 ms) with all data included (bottom). Shaded areas denote significant differences (p < .01, uncorrected), the yellow line at 1330 ms signifies stimulus offset.

In summary, the following ERPs were included in further analysis: post cue spatial cueN1, CNV and emotional N300; post stimulus spatial stimP1, stimN1/N170, SPCN, and emotional LPP. If a component appeared significant both in the spatial and emotional mass univariate analysis with similar topographies, it was not analysed separately but treated as one component. It should also be noted that the early post stimulus negative component is referred to as N1 for the purposes of this study, but could also be interpreted to reflect activity characteristic of the face sensitive N170 component.

For a more detailed investigation of possible effects and interactions, repeated measures ANOVAs were conducted for the selected spatial and emotional components in all combinations of the five factors: (a) cue direction (left/right), (b) emotion position (fearful-fearful/fearful-neutral/neutral-fearful/neutral-neutral), (c) gender position (male-female/female-male), (d) cue type (spatial/emotional), and (e) channel (left/right hemisphere). EEG was averaged relative to a 200 ms pre-cue baseline.

Trials with correct responses were not analysed separately from false responses, as the processes discussed in this study had little to do with the gender discrimination task and largely preceded response giving.

Behavioural performance measures (reaction times, error rates) were analysed with repeated measures ANOVAs for the factors cue direction, emotion position, gender position and cue type. Reaction times were calculated without false responses.

An alpha level of .05 was used for all statistical tests.

All analyses were conducted on MATLAB R2008b, EEGLAB 12.0 and STATISTICA 12.

Results

Behavioural results

Reaction times (RT) and error rates were analysed with repeated measures ANOVAs for the four factors. Mean RT was 820 ms (SD = 370 ms). RTs for the factor Cue Direction (arrow pointing left or right) did not differ significantly, $F(1,32) = 3.31$, $p = .078$, however, the trend indicated that attended stimuli on the left side of the screen were recognised slightly faster than those presented on the right side. There was a significant main effect of Emotion Position, $F(3,96) = 2.72$, $p = .049$. Post hoc comparisons using the Fisher LSD test revealed that RTs were shorter in the experimental condition where two neutral stimuli were paired together, being significantly different from all other conditions with at least one emotional stimulus (p values between .038 and .009). RTs also revealed Cue Direction × Emotion Position ($F(3,96) = 3.56$, $p = .017$) and Emotion Position × Gender Position interactions ($F(3,96) = 6.44$, $p < .001$). RTs were shorter when the attended stimuli were neutral and longer when fearful faces were attended. The face-by-gender interaction with emotion revealed a trend where RTs appeared longest when a fearful female face was presented on the screen, regardless of what was next to it or whether it was attended or not.

Similarly to RTs, error rates also demonstrated an Emotion Position main effect, $F(3,96) = 6.60$, $p < .001$ and an Emotion Position × Gender Position interaction, $F(3,96) = 15.40$, $p < .001$. Post hoc LSD tests revealed that faces in the neutral-neutral task condition were recognised more accurately compared to the three conditions with emotional stimuli (p values $< .003$). Comparatively high in error rates were the two conditions where a fearful female face was paired with a neutral male face. In addition, there was a main effect of cue type, $F(1,32) = 5.31$, $p = .028$, with higher accuracy rates for the emotional cue condition. Average error rates across all participants were 4.8% with no one responding inaccurately on more than 10.9% of the trials.

The pattern of behavioural results suggests that emotional expression tended to compromise the performance of the central task leading to longer response times and increased errors.

Electrophysiological results

Cue evoked early components. As the visual cueP1 component failed to reach a significant difference between the attentional conditions, the earliest ERP component that seemed to be affected by allocation of top-down attention was the cueN1 component measured from O1/2 electrodes between 150-200 ms post cue onset. Repeated measures ANOVAs revealed a Cue Direction × Channel interaction, $F(1,32) = 10.32$, $p = 0.003$ with the contralateral cueN1 amplitude larger at attended compared to unattended trials. There was also a main effect of Emotion Position, $F(3,96) = 3.54$, $p = 0.017$, with post hoc tests revealing that the average cueN1 amplitude was largest in the fearful-fearful face condition, differing significantly from both the neutral-neutral and neutral-fearful conditions, but not from the fearful-neutral task condition. The fearful-neutral and neutral-fearful conditions were also significantly different from each other, indicating that the cueN1 component was more affected by emotion when it was presented in the left visual field. However, there was no significant interaction between Emotion Position and Cue Direction which suggests that this effect of emotion acts independently of whether a stimulus is attended or not. A separate mass univariate analysis of the emotion condition also revealed a significant effect of emotion in the same time frame which was prominent in central posterior electrodes (Figure 4).

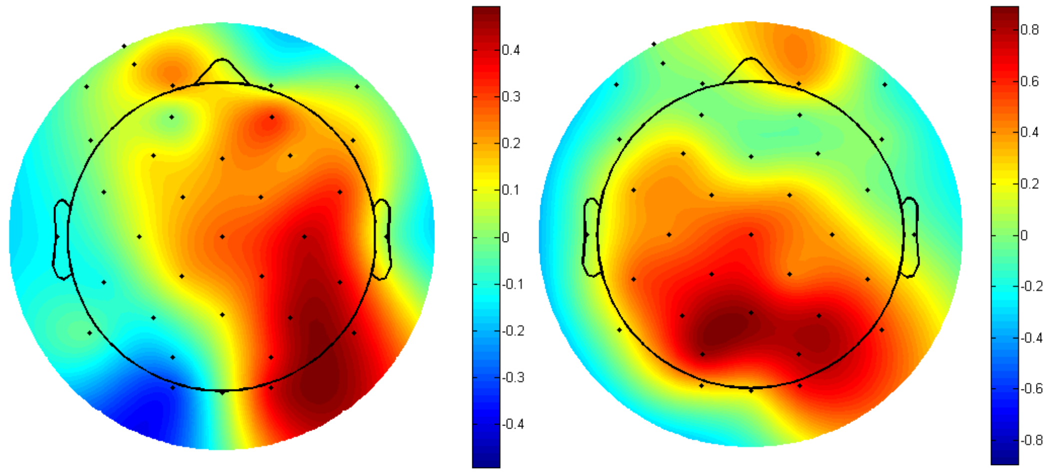

Figure 4. Scalp maps depicting the difference between the two spatial conditions (cue left/cue right) and those between two emotion conditions (fearful-fearful/neutral-neutral) in the cueN1 time frame (150-200 ms post cue onset).

Cue evoked late components. The emotion condition mass univariate analysis revealed a mid-frontal N300 component between 280-350 ms post cue onset which was measured from the Cz electrode where the effect appeared largest (Figure 5). There was a significant main effect of Emotion Position, $F(3,96) = 3.09$, $p = 0.031$ revealing a clear trend of a more negative amplitude in the increasingly emotional conditions. Post hoc tests confirmed that the task condition where two fearful faces were paired together differed significantly from the neutral-neutral and neutral-fearful task conditions.

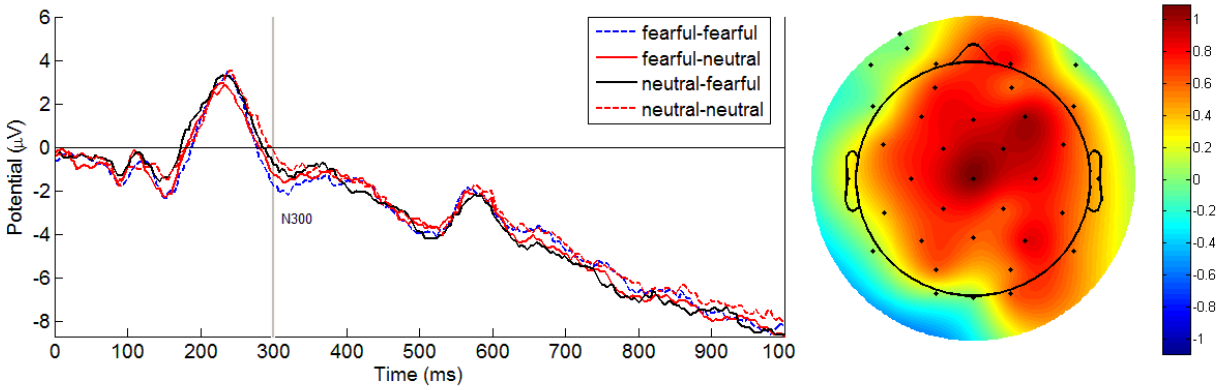

Figure 5. Cz electrode mass univariate analysis (left). Waveforms were averaged over the four emotion conditions. The shaded area denotes significant difference ($p < .01$, uncorrected). Scalp difference map (right) between the fearful-fearful/neutral-neutral conditions in the N300 time frame (280-350 ms post cue).

The negative slow wave (CNV) apparent in the time frame prior to stimulus onset was analysed as two separate components due to different scalp map distributions, both from the C3/4 electrodes. The early CNV 300-500 ms revealed a significant Cue Direction × Channel interaction, $F(1,32) = 19.71$, $p < 0.001$ displaying a more negative amplitude in the attended target condition. However, this effect was only significant over the left hemisphere and not in the right hemisphere. The scalp map in this time frame showed an activation of the left hemisphere, especially over the motor cortex, which could be interpreted as a readiness for responding as the participants responded with their right hand in all conditions. The later 700-1000 ms CNV component also had a significant Cue Direction × Channel interaction, $F(1,32) = 7.32$, $p = 0.011$ with the increased negativity effect at attended locations appearing more prominent in the right hemisphere. Neither of the time frames displayed any significant effects of emotion.

Stimulus evoked early components. The first component to have any significant effects of spatial attention post stimulus was stimP1 measured from the P7/8 electrodes at 80-130 ms post stimulus. There was a significant Cue Direction × Channel interaction, $F(1,32) = 12.50$, $p = 0.001$, showing larger amplitudes for contralateral compared to ipsilateral stimP1. A Channel main effect was also significant $F(1,32) = 16.52$, $p < 0.001$ revealing that the mean stimP1 amplitude was larger when measured from the P8 electrode. The scalp map suggested a slight overlap between the stimP1 and following stimN1 component. The stim N1 was also measured from the P7/8 electrodes at 150-200 ms post stimulus onset. There was a significant interaction of Cue Direction × Channel, $F(1,32) = 30.18$, $p < 0.001$, with the effect of Cue Direction more pronounced in the right hemisphere. The contralateral stimN1 amplitude was smaller on attended compared to unattended trials. A main effect of Cue Type was also found, $F(1,32) = 5.56$, $p = 0.025$ with stimN1 more negative in the spatial cue condition. These early components did not appear to be modulated by emotion, nor were any significant components apparent within these time frames in the emotional mass univariate analysis.

Stimulus evoked late components. The mass univariate analysis revealed a slow posterior contralateral negativity (SPCN) starting approximately at stimulus offset. A significant Cue Direction × Channel interaction ($F(1,32) = 33.91$, $p < 0.001$) was found in the mean amplitudes measured from P7/8 between 330-600 ms post stimulus. The lateral spatial attention effect displayed an enhanced negativity when contralateral to attended stimuli. There was also a significant effect of Cue Type, $F(1,32) = 5.28$, $p = 0.028$ with the negative component slightly attenuated in the Emotional Cue condition.

Emotional effects in this later post stimulus period were observed as an LPP component prominent at central electrodes between 250-600 ms post stimulus onset (Figure 6). There was a significant main effect of emotion, $F(3,96) = 4.48$, $p = 0.005$ with the average amplitude in the fearful-fearful task condition more positive and significantly different from the neutral-neutral and neutral-fearful conditions (post hoc p values 0.002) and less positive but not significantly so in the fearful-neutral condition (post hoc $p = 0.054$). There was also a significant interaction of Gender Position × Cue Type, $F(3,96) = 5.83$, $p = 0.022$. The gender of faces did not have a significant effect in the emotional cue condition, but when only a spatial cue had been presented, the average LPP amplitude was larger if a male face was on the left of the fixation cross and a female face on the right, regardless of facial expression or cue direction (post hoc $p = 0.026$).

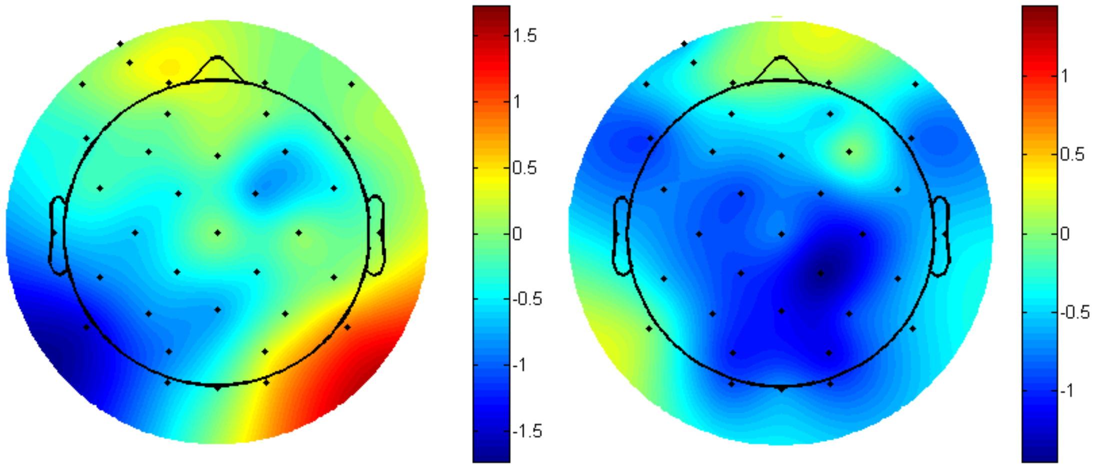

Figure 6. Scalp maps depicting the difference between the two spatial conditions (cue left/cue right) in the late SPCN component (left) and those between two emotion conditions (fearful-fearful/neutral-neutral) in the LPP component (right).

Discussion

The aim of this study was to better understand to what extent and during which stages of processing task irrelevant emotion modulates the neural correlates of stimulus processing and top-down spatial attention.

Results revealed that the distraction effect of task irrelevant emotion was clearly visible in behavioural results, but was not reflected as a modulatory influence on ERP components affected by the allocation of spatial attention. Emotion appeared more present at a later stage of processing, suggesting that the distraction effect of emotion was a result of sustained attention and slowed disengaging from emotional stimuli, rather than an automatic capture of attention at an early stage of processing. Even at the later stage, no interactions between emotion and spatial attention were observed, implying that the two mechanisms act independently.

Behavioural results

Reaction times were significantly slower for emotional targets compared to neutral ones. A main effect of emotion indicated that whether attended or not, the mere presence of an emotional face on the screen slowed reaction times compared to the task condition where two neutral stimuli were paired together. Error rates also displayed a clear effect of emotion as more mistakes were made in conditions with at least one fearful face. A left visual field bias which is frequently reported, especially when processing facial stimuli (Bourne, 2008), was also present in our study as targets in the left visual field were recognised slightly faster than those on the right, but the effect was not significant. Both reaction times and error rates displayed interactions between emotion and gender, implying that the distraction effect of emotion in the gender discrimination task might have been related to the phase in which facial structure and identity is processed. Several studies have reported that emotion related features of facial expression can affect the ease with which gender judgements are made by making faces appear more typically male or female (Becker, Kenrick, Neuberg, Blackwell, & Smith, 2007; Hess, Adams, Grammer, & Kleck, 2009).

Early anticipatory components

The earliest visual cueP1 component was not affected by cue direction which is unsurprising as it has been found that central cues induce a voluntary shift of attention with a relatively slow onset time of at least 200 ms (Müller & Rabbitt, 1989). The first component to reveal a significant difference of the Cue Direction factor was the cueN1 component measured from occipital electrodes 150-200 ms post cue onset, with a larger amplitude in the attended trials. The cueN1 also displayed a significant effect of emotion, with the amplitudes largest when the emotional cues predicted the appearance of two fearful faces together (two red circles) and significantly smaller on trials where two neutral faces were set to appear (two green circles) or where the emotional face would be presented on the right side (a green and a red circle). The effect was also obvious from the emotion condition mass univariate analysis and could be observed in all central posterior electrodes. The fact that this emotion effect was significantly different between the two conditions where the coloured circles predicted a fearful face being paired with a neutral one, and stronger when the emotional stimulus would be presented on the left side, implies that the left visual field was processed preferentially or in a more emotion sensitive manner (Bourne, 2008). Despite the presence of an emotion effect on the cueN1 component, emotion did not interact with cue direction which would indicate that both modes of attention were acting independently, possibly only reflecting similar patterns due to partially overlapping topographies (Figure 5). Nevertheless, it should be noted that this emotion effect, while relatively short in latency, was produced by an emotional cue and therefore may not be perfectly comparable to the actual processing of the features of fearful faces.

A mid-frontal negative N300 component was also observed exclusively in the emotion condition mass univariate analysis. Repeated measures ANOVAs confirmed a significant effect of emotion, with the amplitude enhanced in the more emotional conditions. Enhanced N300 amplitudes have previously been associated with affective evaluation and depth of emotional processing (Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005). This effect appeared completely independent of top down attention, as it was not modulated by cue direction nor did it have any modulatory effects on the components sensitive to spatial attention. This was the only anterior ERP component where any emotional effects were observed. The N300 component appears specific to picture stimuli, but sensitive to the semantic, rather than the physical properties of a picture identification task (Hamm, Johnson, & Kirk, 2002). This could explain why the N300 component was not observed in the post stimulus time frame, but solely after the presentation of cues whose emotional meaning could only be inferred through association and not actual physical properties.

Preparatory attention

The slow CNV wave which represents preparatory attention was measured in two segments before stimulus onset (300-500 ms and 700-1000 ms post cue). CNV was larger when contralateral to the attended stimulus in both time frames. Despite some earlier emotion effects at the N1 and N300 latencies, no emotional effects modulated the CNV components nor was there any other emotion sensitive activity in this time frame. As the CNV component is consider to be predominantly reflective of the planning of a motor response, which is supported by the fact that it appeared strongest over the motor cortex areas (electrodes C3/4), it stands to reason that CNV is largely under the control of voluntary, top-down attention and any automatic emotion effects would not be reflected at this level of preparation.

Alternatively, the possible influence of emotion on preparatory attention could also be observed as the modulatory effects of cue type. On a behavioural level, there was a main effect of cue type in error rates, with higher accuracy rates in the emotional cue condition. It would seem that being able to predict the emotional valence of upcoming stimuli reduces some of its distraction quality. Perhaps as a result of allowing the automatic emotional reaction to occur at an earlier latency (cueN1, N300), thereby leaving time for reallocation of attention towards target stimuli before its appearance. Future studies are needed to explicitly test this possibility.

A main effect of cue type was also present in the stimN1 and SPCN components. In both cases the emotional cue condition attenuated the negative amplitudes. The SPCN is considered to reflect the maintenance of visual information in working memory and is enhanced at posterior electrode sites contralateral to the position of the memory items (Eimer & Kiss, 2010; McCollough, Mchizawa, & Vogel, 2007). SPNC amplitudes are larger as the number of maintained memory representations increases (McCollough et al., 2007). A smaller SPCN amplitude in the emotional cue condition supports the proposed idea that by enabling some emotional effects to take place before stimulus onset, the emotionally informative cue leaves more room in the working memory during stimulus processing, resulting in less erroneous responses and smaller SPCN amplitudes. Since the post stimulus stimP1 and stimN1 components overlap to a degree, it cannot be said with certainty which component produced the cue type effect. Although only significant when measured at the stimN1 latency, emotional cue type also resulted in a more positive amplitude in the stimP1 time frame. Nevertheless, recent studies have found that N1 amplitudes can also be attenuated by predictive mechanisms (Lange, 2013; Timm, SanMiguel, Saupe & Schröger, 2013).

Early stimulus processing

Following task instructions and attending to the left or right visual field as indicated by the arrow cue produced expected ERP components. The early visual stimP1 and stimN1 components were measured at lateral posterior electrodes between 80-130 ms and 150-200 ms after stimulus onset, respectively. The stimP1 component was enhanced in the attended condition which is in keeping with earlier findings (Hillyard & Anllo-Vento, 1998). The stimN1 component, however, appeared attenuated in the attended condition. This could be explained by an overlap between the stimP1 and stimN1 components, as they are adjacent temporally and similar topographically, with the enhanced positivity to attended faces extending over to the stimN1 latency range (Feng, Martinez, Pitts, Luo, & Hillyard, 2012) and has been also found in earlier studies (Handy & Khoe, 2005; Wijers & Banis, 2012). Neither of these components was affected by difference in facial expression nor did the mass univariate analysis reveal any other early components sensitive to emotion after stimulus onset.

Studies that have found rapid automatic emotion effects in ERPs have reported an enhanced positivity for emotional (predominantly negative) relative to neutral faces between 100-200 post stimulus (Eimer, Holmes, & McGlone, 2003; Pourtois et al 2005; Rellecke, Sommer, & Schacht, 2012), as well as an enhanced negativity at lateral posterior electrodes in the form of modulations of the N170 component (Batty & Taylor, 2003; Blau, Maurer, Tottenham, & McCandliss, 2007) or the presence of an early posterior negativity (EPN) component between 200-300 ms after stimulus onset (Aguado et al., 2012; Eimer et al., 2003; Schupp et al., 2004). The absence of these modulations in the present data suggests that the early allocation of attention resources was dominated by top-down mechanisms and thereby remained insensitive to the task irrelevant emotional saliency of the stimuli.

Late stimulus processing

The slow posterior contralateral negativity (SPCN) measured from lateral posterior electrodes after stimulus offset displayed a larger amplitude in the attended compared to unattended trials, supposedly displaying the effect of top-down attention on sustaining relevant targets in the working memory (McCollough et al., 2007). There were no effects of emotion in the long 330-600 ms post stimulus time frame, suggesting that emotion did not interfere with the task relevant goal on a neocortical level during or after stimulus presentation. Nevertheless, at similar latencies a slow LPP wave sensitive to the emotion condition was observed at central posterior electrodes, revealing a significant main effect of emotion with the most positive amplitudes in trials where two fearful faces were paired together. The LPP component did not appear to be modulated by top down attention on a significant level. Previously it has been found that the LPP can be sensitive to a number of regulatory factors, including reappraisal of affective stimuli in a less emotional way and directing attention away towards the neutral features of an emotional stimulus (Foti & Hajcak, 2008). However, it would appear that attending to the non-emotional features of a fearful face cannot suppress the effects of emotion, especially on trials where the face next to it is also fearful. The LPP displayed a smaller amplitude on trials where at least one of the faces was neutral, regardless of which face was attended. This again confirms that top-down attention had little or no effect on the emotion sensitive LPP component which instead seemed to robustly reflect the degree of emotional information present on the screen. There was also an interaction of gender and cue type with gender effects present only on the trials where no emotional cue was presented, with amplitudes larger if a male face was on the left and a female face on the right side.

Emotion and gender

Although not the main focus of this study, the results revealed some intriguing interactions between the emotional expression and the gender of the faces which deserve to be discussed separately. The classic model by Bruce and Young (1986) proposed that the visual processing of facial expression and identity (including gender) take place in two separate, non-interacting routes. However, several recent studies have disputed this theory by demonstrating ways in which the facial expression of a face can contribute to the categorisation of gender and vice versa. For instance, it has been found that certain combinations of expression and gender (e.g. a happy female, fearful female or an angry male) are recognised faster than its counterparts (e.g. a happy male, fearful male or an angry female) (Aguado, García-Gutierrez, & Serrano-Pedraza, 2009; Becker et al., 2007; Hess et al., 2009). It has been suggested that some features can serve both as markers of emotion as well as that of masculinity/femininity or dominance/affiliation—thicker eyebrows and a square jaw being more characteristic of both masculine and angry faces and a more rounded face with large eyes typical of females and happy or fearful expressions (Hess et al., 2009). Contrary to expectation, however, the behavioural results in this study displayed a different pattern. It would appear that the mere presence of a fearful female face on the screen slowed reaction times significantly and also resulted in more errors, although one might assume that a fearful male as the more surprising combination would instead take more effort and time to process. As this experiment explored the effects of emotion using only fearful faces (male and female), it could be hypothesised that the expression of the fearful female was perceived as more “real” or sincere and thus the distraction effects of emotion (both preferential capture of attention and slowing of disengagement) were more marked on trials where the emotion was presented on a female face, even when that face was unattended. ERP results suggested that all gender-emotion interactions were present only when the emotion had been unannounced (spatial cue condition). Although so far behavioural measures have dominated this line of studies, results from this, as well as another recent ERP study (Valdés-Conroy et al., 2014) indicate that the interactions of gender and emotional expression can at least to some extent be traced to the neocortical level of the late processing of faces and that ERPs might prove valuable in trying to explain the mechanisms behind the often puzzling interactions observed in behavioural results.

Conclusion

The results of the current study show that task irrelevant emotion does not have any modulatory effects on top down attention as reflected by the early ERP components. It would seem that by the time that the faces appeared, spatial attention was already allocated to the task-relevant location in anticipation of stimulus appearance (as indicated by the CNV component) and neither emotional features present at the attended location nor those belonging to distractor stimuli at unattended locations managed to produce a difference in the early visual components. This would imply that any automatic capture of the subcortical affective attentional pathways that might have occurred did not translate onto the neocortical level and thus did not affect top-down attention during the early processing of visual stimuli.

Nevertheless, it cannot be said that no early effects of emotion were observed at all. In the post cue time frame, the appearance of an emotional cue predicting the onset of a fearful face (preferentially when presented to the left visual field) resulted in increased amplitudes of the cueN1 component, independently of cue direction. It can be hypothesised that since top-down attention was not fully allocated to the cued location prior to the cueN1 latency (as indicated by the lack of any spatial attention effects on the cueP1 component) and since the gender discrimination task required no additional resources prior to the appearance of the faces, top-down attentional resources were still available for processing emotional features during the cueN1 time window. On the other hand, after stimulus onset spatial attention was already firmly locked at the cued location and could henceforth only be actively directed away from said location by a stimulus salient enough to override task relevancy.

In addition to the cueN1 component, emotion effects were also observed in the form of a midfrontal negative wave approximately 300 ms post cue onset which can be explained as the result of semantic processing of the emotional meaning of the presented cues.

As the interfering quality of emotional features came through very clearly in behavioural results, it stands to reason that the subcortical affective attention would be expected to have some observable modulatory effects on top-down attention as reflected by ERPs. Interestingly, no significant interactions between emotion and top-down attention were observed in the late SPCN or LPP components which shared a similar latency, but different topographies (Figure 6), and appeared to therefore reflect different modes of attention working independently and processing different features of the same stimuli in a parallel fashion. Since it has been previously found that the LPP can be modulated by top-down attention and task conditions, it is possible that it was affected by cue direction to a degree, but failed to reach statistical significance. Alternatively, the LPP and SPCN may simply reflect independently operating attention mechanisms whose interaction, suggested to take place by behavioural results, remained invisible for ERPs due to, for example, lack of phase-locking to stimulus onset.

In conclusion, it can be said that any effects of task irrelevant emotion on ERPs appeared to take place independently of top-down attention. Despite the relatively low demanding task of gender discrimination, it seems that affective attention was effectively suppressed until a much later stage when the primary task of processing the non-emotional features of faces had already been completed to some extent, possibly putting into use the attentional resources left over from the simple task. Although acting independently of top-down attention even at the later latencies, behavioural results indicate that sustained attention on emotional faces, as reflected by the LPP, resulted in slowed disengagement from fearful faces and thereby interfered with the task goal of responding in a fast and accurate manner. The possible mechanisms through which these interactions occur, still leave some room for debate.

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Lihtlitsents lõputöö reprodutseerimiseks ja lõputöö üldsusele kättesaadavaks tegemiseks

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1. annan Tartu Ülikoolile tasuta loa (lihtlitsentsi) enda loodud teose „Task irrelevant emotion effects on top-down attention", mille juhendaja on Andero Uusberg

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