



Research Report

Attention is prioritised for proximate and approaching fearful faces



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ABSTRACT

Attention is an important function that allows us to selectively enhance the processing of relevant stimuli in our environment. Fittingly, a number of studies have revealed that potentially threatening/fearful stimuli capture attention more efficiently. Interestingly, in separate fMRI studies, threatening stimuli situated close to viewers were found to enhance brain activity in fear-relevant areas more than stimuli that were further away. Despite these observations, few studies have examined the effect of personal distance on attentional capture by emotional stimuli. Using electroencephalography (EEG), the current investigation addressed this question by investigating attentional capture of emotional faces that were either looming/receding, or were situated at different distances from the viewer. In Experiment 1, participants carried out an incidental task while looming or receding fearful and neutral faces were presented bilaterally. A significant lateralised N170 and N2pc were found for a looming upright fearful face, however no significant components were found for a looming upright neutral face or inverted fearful and neutral faces. In Experiment 2, participants made gender judgements of emotional faces that appeared on a screen situated within or beyond peripersonal space (respectively 50 cm or 120 cm). Although response times did not differ, significantly more errors were made when faces appeared in near as opposed to far space. Importantly, ERPs revealed a significant N2pc for fearful faces presented in peripersonal distance, compared to the far distance. Our findings show that personal distance markedly affects neural responses to emotional stimuli, with increased attention towards fearful upright faces that appear in close distance.

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1. Introduction

Attention is an important cognitive process that allows the prioritisation of specific stimuli in our environment for further evaluation. This is particularly relevant when stimuli warn of

potential danger, for example in detecting the presence of a potential predator in the environment.

In the field of face processing, electrophysiological evidence with EEG has shown that the visual system prioritizes attention towards fearful faces compared to other expressions (Holmes,

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Green, & Vuilleumier, 2005; Santesso et al., 2008), in particular using a component linked to attention termed the N2pc. The N2pc, characterized as a larger negativity appearing over electrodes contralateral to the side of the attended stimulus compared to ipsilateral electrodes, occurs approx. 200–320 msec post stimulus onset at posterior scalp sites and has been found to reflect selective attention (Holmes, Bradley, Nielsen, & Mogg, 2009; Kiss, Van Velzen, & Eimer, 2008). Eimer and Kiss (2007) investigated how attention, as indexed by this N2pc component, was influenced by a task-irrelevant fearful face presented among other, non-threatening neutral expressions. Even though participants were asked to respond to a luminance change at the centre and to ignore the surrounding faces, an N2pc was observed in response to a fearful face surrounded by neutral other faces. By contrast, there was no N2pc towards a neutral face among fearful faces, indicating that attention is prioritised towards a potentially threatening face. Corroborating this interpretation, behavioural studies have revealed that RTs were faster when detecting a fearful face in visual search or in a dot probe task (Armony & Dolan, 2002; Carlson & Reinke, 2008; Pourtois, Grandjean, Sander, & Vuilleumier, 2004).

Other studies reported that fearful faces can also modulate the N170, a component thought to reflect face processing. The N170 is a bilateral negative deflection, usually predominant over the right hemisphere, that appears about 170 msec after the presentation of a face compared to other non-face stimuli (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000a; Rossion, Joyce, Cottrell, & Tarr, 2003). Furthermore, when faces are presented bilaterally rather than centrally, this component can be observed as a larger negativity contralateral to the relevant face (lateralised N170; Burra & Kerzel, 2019; Towler & Eimer, 2015; Towler, Kelly, & Eimer, 2016). In one study, fearful faces were found to modulate the amplitude of the N170, with a larger negativity for fearful faces in comparison to other emotional expressions (Blau, Maurer, Tottenham, & McCandliss, 2007). It has been suggested that this effect may result from an enhancement of the visual response due to feedback projections from the amygdala to associative visual areas (Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004).

A distinct and less explored topic is the effect of personal distance on neurophysiological responses. A small number of fMRI studies have demonstrated that fearful/threatening stimuli activate fear-related areas more markedly when they appear to be situated physically closer to the viewer (Coker-Appiah et al., 2013; Mobbs et al., 2010). For instance, Mobbs et al. (2010) measured brain activity while participants were shown a simulated spider that appeared either at a far distance, or close to the participant's foot. When the spider was closer, an increased activation was observed, particularly in the amygdala. Other investigations have shown that when irrelevant stimuli (e.g., meaningless shapes) appear close to the participant, they are attended more rapidly than when they appear at a greater distance (Chen, Weidner, Vossel, Weiss, & Fink, 2012; Kasai, Morotomi, Katayama, & Kumada, 2003). By contrast, in humans, damage to the amygdala appears to disrupt the processing of personal space. Indeed, Kennedy, Glascher, Tyska, and Adolphs (2009) studied a patient with bilateral damage to this structure and observed a loss of the sense of personal space in this individual.

These observations open the possibility that distance (physical or perceived) can modulate the processing and attentional capture of fearful faces, effects that would be reflected on the N170 and the N2pc. To our knowledge, this has yet to be investigated with the use of EEG or combining distances with emotional faces. EEG measures have extensively demonstrated good temporal resolution and have revealed the neural timing of events associated with both face processing (N170 component) and attention (the N2pc component) (Burra & Kerzel, 2019; Eimer & Kiss, 2007). We therefore used EEG in this study to determine the neural dynamics associated with the encoding and attentional capture of fearful faces, as indexed by the lateralised N170 and N2pc components, in particular to determine how proximity modulates these processes.

In the first experiment, we reasoned that if attention was biased towards fearful faces that potentially entered personal space, this would be reflected in a larger N2pc to approaching (looming) fearful face compared to receding fearful faces, or control stimuli, which were looming neutral and inverted faces. However, another possibility could be that fearful faces attract attention regardless of looming or receding motion, which would produce an N2pc to upright fearful faces in general.

2. Experiment 1

In Experiment 1, participants completed a task at the centre of the screen by responding to changes of a letter 'H' into an odd or even number. Participants were instructed to ignore all looming and receding faces that appeared on the screen on either side of the fixation letter task. Simultaneously, a fearful and a neutral face appeared bilaterally, one of which dynamically increased in size ('looming'), while the other decreased in size ('receding'). As a control, inverted fearful and neutral faces were also presented and were counter-balanced with the upright stimuli. This was done as inverted faces possess identical low-level features as their upright counterparts while at the same time precluding the recognition of the emotional expression (see for example, Parks, Coss, & Coss, 1985). These behavioural observations have been corroborated by electrophysiological investigations, which have shown that ERP differences caused by facial expressions are cancelled out by face inversion (Eimer & Holmes, 2002).

These looming/receding stimuli were used to establish whether attention would be biased either towards fearful faces approaching the viewer, or to looming faces in general.

2.1. Methods

We report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study.

2.1.1. Participants

The sample size was determined using the minimum effect size of Cohen's d_z 1.5 for a significant lateralised N170

component from Burra and Kerzel (2019). A power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) was conducted with the following parameters: effect size (Cohen's d_z) of 1.5, alpha at .001 and power .90. This revealed a sample size of 15 participants were required.

Fifteen right-handed participants (10 females) from the University of Queensland, with normal or correct to normal vision, and no known neurological condition took part in Experiment 1. Mean age was 22.73 years ($SD = 2.02$; range: 20–29). Participants gave their informed consent prior to participation and were reimbursed with AU\$20 for their time. The protocols for all studies reported here were approved by the Human Ethics Committee at the University of Queensland, Australia.

2.1.2. Apparatus

EEG data were recorded using a 64-channel Biosemi EEG system (Amsterdam, The Netherlands) with an AD-Box Active-Two amplifier connected to a personal computer. The personal computer contained an Intel(R) Core(TM) i7-4790 CPU, equipped with an NVIDIA GeForce GTX 745 graphics card and controlled by Python-based Psychopy software (Peirce et al., 2019). A standard USB mouse and keyboard were used to collect manual responses. The stimuli were displayed on a 28" colour LCD monitor with a resolution of 1920×1080 pixels and a refresh rate of 60 Hz. Participants were tested individually in a normally lit laboratory with an approximate viewing distance of 76 cm.

2.1.3. Stimuli

Faces were presented against a grey background (RGB: 125, 125, 125) and the 24 grey-scale faces (twelve female and twelve male faces, half fearful and half neutral faces) were obtained from the Ekman Face database (Ekman & Friesen, 1976; see Fig. 1). The letter 'H' (font = Arial, height = 40 pixels, colour = black) was presented at the centre of the screen at the start of the trial for 1,300 msec and changed to either an odd or even number (numbers 0–9, font = Arial, height = 40 pixels, colour = black). Two faces were presented on either side of the fixation point 3.16° from the fixation point to the centre of the image. The faces were first presented at the same size, with a height of 3.61° and width of 2.41° . Over the course of 300 msec, one of the faces decreased at a rate of 2.2 uniformly on the x and y axis until the size was 3.01° in height and 1.66° in width, while the other face increased at a rate of 2.2 uniformly on the x and y axis until the size was 4.36° in height and 3.16° in width. Thus, one face increased in size so as to 'loom', while the other decreased in size so as to 'recede' from the participant.

A fearful face was always presented in conjunction with a neutral face and upright faces appeared equally often as inverted faces. The inverted faces were created by rotating the upright face image by 180° . The mean brightness of each stimulus combination was checked with a Python-based script, and the results confirmed that there was no difference in mean brightness between any of the different combinations of faces displayed.

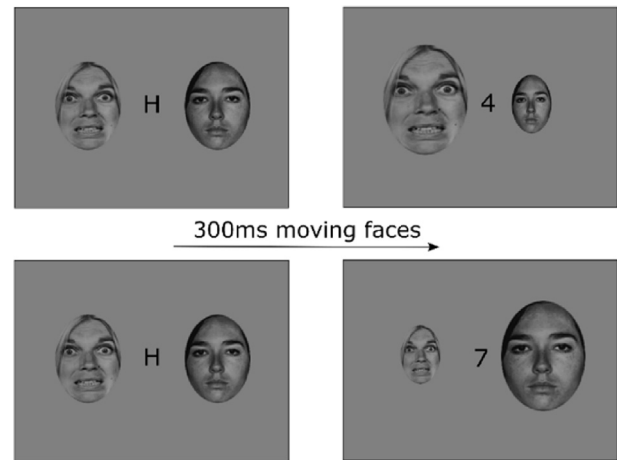


Fig. 1 – Experiment 1 stimuli. The letter 'H' (fixation) was presented at the centre of the screen for the first second. Two faces then appeared on either side of fixation at an equal size, with one face immediately increasing in size ('looming') and the other decreasing ('receding'), over the course of 300 msec. The faces were irrelevant to the task, which was to report whether the 'H' changed to an odd or even number. Upright faces fearful or neutral faces were presented, with a looming motion on one side associated with a receding movement on the other. Inverted faces were used as control stimuli (images not to scale).

2.1.4. Design and procedure

Experiment 1 used a 2 (Face Orientation: Upright, Inverted) \times 2 (Looming Expression: Fearful, Neutral) \times 2 (Laterality of Looming Stimulus: Contralateral, Ipsilateral) within-subjects design. On each trial, there was always one fearful face presented with a neutral face in order to isolate ERP effects to the fearful face. Upright and inverted paired faces were equally represented in each block. The intertrial interval was 1,000 msec (starting after the response was entered), during which time, only the letter 'H' was visible on the screen. At the end of the 1,000 msec intertrial interval, alongside the centre 'H', two faces appeared which immediately began changing in size at a steady rate over the course of 300 msec at which point they would stop, and an odd or even number replaced the 'H'. Participant indicated with their response whether the number was odd or even, and all stimuli remained visible until the response was recorded.

Blocks consisted of 16 different combinations of faces: 2 (side of fearful expression: left vs. right) \times 2 (side of looming motion: left vs. right) \times 2 (face orientation: upright vs. inverted) \times 2 (gender of face: same gender vs. different gender). Identities appeared in a pseudo-random order with the constraint that we never presented the same model on the same trial (i.e., a given actor's neutral expression on one side simultaneously with their fearful expression on the other). Repeating these combinations four times led to a total of 64 trials per block, and participants completed a total of 10 blocks (640 trials).

Participants were informed both verbally and using on-screen instructions. They were instructed to keep their eyes fixated at the centre of the screen on the letter 'H', and to respond by pressing the 'z' key when the letter changed to an even number, or the 'm' key when the letter changed to an odd number. Participants were told to ignore the faces that appeared laterally.

The experiment took approximately 25 min to complete.

2.1.5. Data analysis

Data were analysed with repeated measures ANOVA, and paired two-tailed t-tests, using the statistical program JASP (JASP Team, 2017). ERP plots were created in R using 'reshape2' (Wickham, 2007), and 'ggplot2' (Wickham, 2009) packages (R Core Team, 2016). Effect sizes were reported as partial eta squared (η_p^2) and Cohen's *dz*.

For the behavioural data, trials were excluded from further analysis when they contained fast (i.e., below 200 msec) or slow responses (i.e., greater than 2000 msec), leading to a loss of 3.15% of the data.

EEG trials were excluded from analysis when they contained blinks (2.68%), horizontal eye movements (17.48% of trials), were incorrect (4.28% of trials) or anticipatory responses (i.e., less than 200 msec) or delayed responses (i.e., greater than 2,000 msec; 3.15% of trials). This left 72.42% (6,952 trials in total and on average there were 58 trials per condition) of the trials for data analyses across all subjects (an average of 436.47 trials per participant).

2.1.6. EEG data recording and analysis

Continuous EEG was measured at 1024 Hz using an AD-Box ActiveTwo amplifier (Amsterdam, The Netherlands), using 64 channels placed in an elastic cap according to the international 10–10 system. Impedances were kept below 30 k Ω and horizontal eye movements were measured with external electrodes placed on the outer canthi of the eyes. For the on-line recording, the data was sampled at a rate of 1024 Hz, with a low pass filter of 40 Hz and a high pass filter of .16 Hz. EEG data were analysed with Brain Vision Analyzer 2.0 software (Brain Products, Gilching, Germany). All electrodes were re-referenced to the average of all scalp electrodes (i.e., electrodes AF3, AF4, AF7, AF8, C1, C2, C3, C4, C5, C6, CP1, CP2, CP3, CP4, CP5, CP6, CPz, Cz, F1, F2, F3, F4, F5, F6, F7, F8, FC1, FC2, FC3, FC4, FC5, FC6, FCz, Fp1, Fp2, Fpz, FT7, FT8, Fz, Iz, O1, O2, Oz, P1, P2, P3, P4, P5, P6, P7, P8, PO3, PO4, PO7, PO8, POz, Pz, T7, T8, TP7, and TP8), and the data was resampled at 500 Hz, with a high cut off filter of 35 Hz, and a low cut off filter of .1 Hz.

Trials were excluded from further data analysis if they contained blinks exceeding ± 60 μ V in the Fpz channel, horizontal eye movements exceeding ± 40 μ V in the HEOG channel (i.e., left canthus minus right canthus; for one participant only the left canthus was used due to excessive noise in the right canthus), or muscle movements exceeding ± 80 μ V in all other channels. The data was segmented into epochs from 100 msec prior to the stimulus onset, to 400 msec post stimulus, relative to a 100 msec pre-stimulus baseline.

ERP waveforms were computed for the looming fearful face (i.e., fearful face was contralateral, and receding neutral face was ipsilateral), looming neutral upright face (i.e., neutral face was contralateral, and receding fearful face was

ipsilateral), looming inverted fearful face (i.e., inverted fearful face was contralateral, and receding inverted neutral face was ipsilateral), looming inverted neutral face (i.e., inverted neutral face was contralateral, and receding inverted fearful face was ipsilateral). Electrodes were termed contralateral and ipsilateral with respect to the side of the looming face. Thus, for example, when a looming fearful face was on the left, electrodes on the left were considered ipsilateral and those on the right were considered contralateral. For both experiments, topographic maps were computed by taking the amplitude differences between contralateral and ipsilateral electrodes. Epochs were determined from previous studies and visually based on where the component was most evident across all conditions. Mean lateralised N170 amplitudes were computed using the epoch of 140–200 msec post-stimulus (similar epoch used by Burra & Kerzel, 2019) and the mean amplitudes for the N2pc from the epoch of 240–280 msec post-stimulus (similar epoch used by Eimer & Kiss, 2007; Holmes et al., 2009), using the average of four electrode pairs that typically show the N2pc and N170 components: PO7/PO8, P7/P8, PO3/PO4 and O1/O2¹. Any significant N170 effects reported in Experiment 1 and 2, always refers to increased negativity contralateral compared to ipsilateral to the approaching face, hence the term *lateralised* N170 (*l*-N170). None of the study procedures or analyses were pre-registered. The data and scripts for both experiments can be found on the Open Science Framework using the following link: <https://osf.io/zg89x/>

2.2. Results

2.2.1. Behavioural results

Overall, accuracy rates were high with 93.44% (*SEM* = 2.16) for Experiment 1. A 2 (Face Orientation: Upright, Inverted) \times 2 (Looming Emotion: Fearful, Neutral) repeated measures ANOVA found no significant main effects or interactions in the mean RTs, all *ps* > .0713 or the mean error rates, all *ps* > .298. Hence, the emotional faces or their orientation did not interfere with the central task of identifying the number at the centre.

2.2.2. ERPs towards fearful faces

2.2.2.1. MEAN LATERALISED N170 (*l*-N170) AMPLITUDE. A 2 (Face orientation: Upright, Inverted) \times 2 (Expression of looming face: Fearful, Neutral) \times 2 (Laterality of looming: Contralateral, Ipsilateral) repeated measures ANOVA was performed over the mean amplitudes for the *l*-N170 in the first epoch of 140–200 msec. A main effect of Laterality of looming was found, $F(1, 14) = 4.84$, $p = .045$, $\eta_p^2 = .26$, with contralateral electrodes ($M = -.40$, *SEM* = .73) showing greater negativity for the looming face, compared to ipsilateral electrodes ($M = -.22$, *SEM* = .69). There were no other significant interactions or main effects, all *F*s < 4.01, all *ps* > .064.

Paired t-tests for each condition comparing contralateral and ipsilateral amplitudes showed only a significant *l*-N170 (i.e., larger negativity contralateral compared to ipsilateral negativity) towards the looming fearful upright face, *t*

¹ Channels PO7 and PO8 were also analysed on their own and showed the same pattern of results (data available on request).

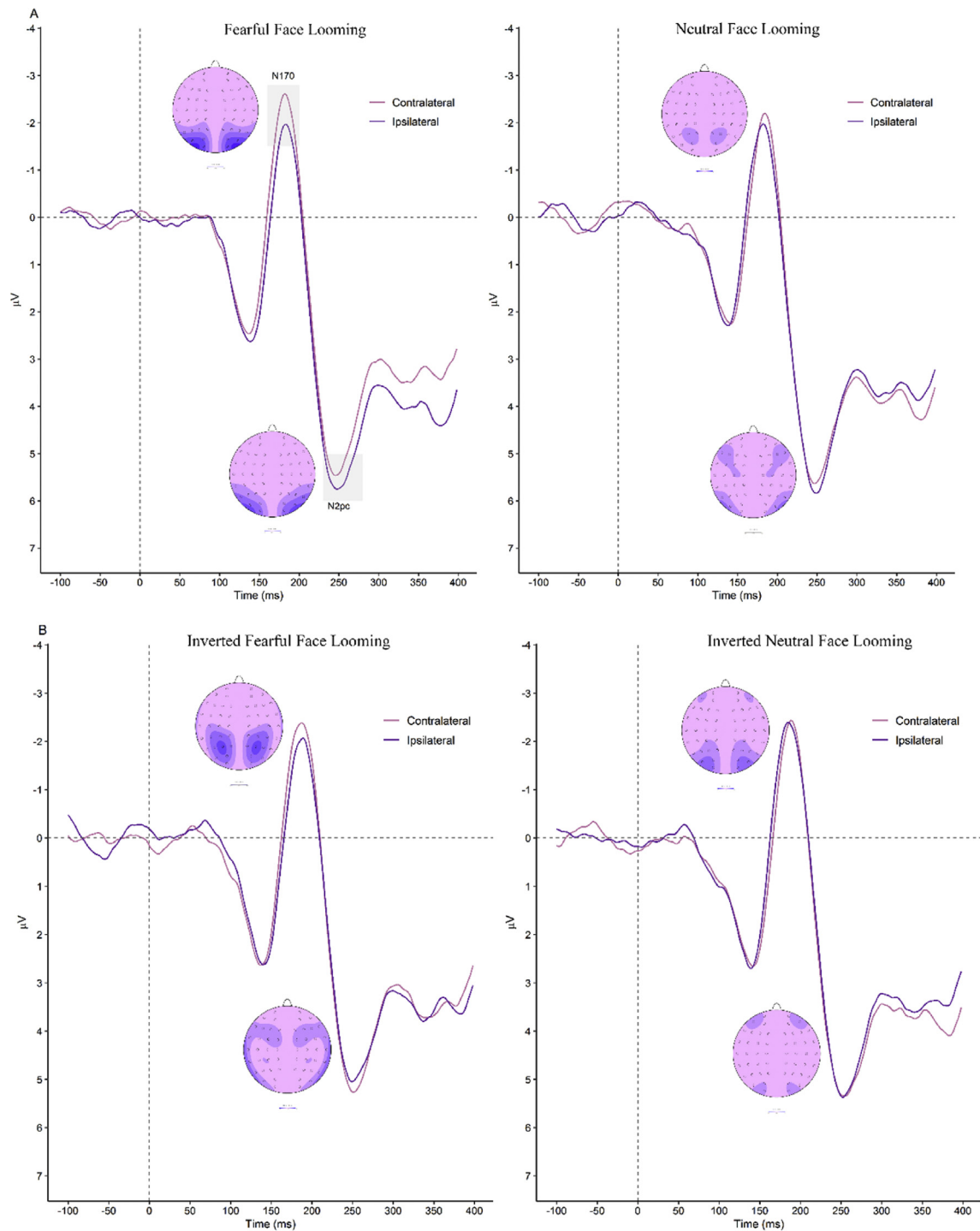


Fig. 2 – ERPs averaged over electrode sites PO7/PO8, P7/P8, PO3/PO4, and O1/O2 for Experiment 1. Pink lines represent contralateral and dark purple lines represent ipsilateral. Topographic maps highlight the amplitude difference between contralateral minus ipsilateral, with a scale of .5 μV to $-.5 \mu\text{V}$. A) A significant l-N170 (epoch: 140–200 msec) was found only for the upright fearful looming face. A significant N2pc (epoch: 240–280 msec) was found only for the upright looming fearful face. B) No reliable component was found for the inverted faces.

(14) = -2.60 , $p = .021$, $d_z = -.67$ (see Fig. 2a), however this effect was not observed for the looming upright neutral face, looming inverted fearful or neutral faces, all t s < 1.90 , all p s $> .078$.

An analysis of the l-N170 difference waves (contralateral minus ipsilateral electrodes) showed that the l-N170 component was significantly more negative for the upright looming fearful face, compared to the inverted neutral looming face, t

(14) = -2.19 , $p = .046$, $dz = -.57$. However, the amplitudes for the upright fearful looming face did not significantly differ from the amplitudes for the upright looming neutral face, or inverted looming fearful face, all $ts < 1.79$, all $ps > .096$.

2.2.2.2. MEAN N2pc AMPLITUDE. The same $2 \times 2 \times 2$ repeated measures ANOVA comparing the mean N2pc amplitudes in the 240–280 msec epoch revealed a significant interaction between Face Orientation and Laterality of looming, $F(1, 14) = 11.83$, $p = .004$, $\eta_p^2 = .46$ (see Fig. 2a). However, there were no other significant main effects or other interactions, $F < 2.81$, $p > .116$.

Subsequent paired t -tests between contralateral and ipsilateral revealed a significant N2pc only for the looming upright fearful face, $t(14) = -2.50$, $p = .026$, $dz = -.65$. There was no significant N2pc for the looming upright neutral face, looming inverted neutral or looming inverted fearful faces, all $ts < 1.40$, all $ps > .185$. An analysis of the N2pc difference waves (contralateral minus ipsilateral) comparing the upright fearful looming face to the other three conditions showed that the upright looming fearful face had a significantly larger negativity than the inverted looming fearful face, $t(14) = -2.91$, $p = .012$, $dz = -.75$ (see Fig. 2a,b), however there was no difference when compared to the upright looming neutral face or the inverted looming neutral faces, all $ts < 1.72$, all $ps > .109$.

2.2.2.3. HORIZONTAL EYE MOVEMENTS (HEOG). To measure if horizontal eye movements differed across conditions, a slightly different analysis was conducted, with a 2 (Face Orientation: Upright, Inverted) \times 2 (Expression of looming face: Fearful, Neutral) \times 2 (Side of looming face: Left, Right) repeated measures ANOVA over the mean amplitudes for the HEOG channel in the first epoch for the l-N170 of 140–200 msec. This revealed no significant main effects or interactions, all $Fs < 2.68$, all $ps > .123$.

To compare the main four conditions, HEOG amplitudes were averaged over Left and Right looming faces per condition (e.g., left approaching upright fearful face and right approaching upright fearful faces were averaged together, etc.). Paired t -tests compared whether HEOG amplitude differed across any of the four conditions. There were no significant differences in amplitudes when comparing any of the conditions to one another, all $ts < 1.60$, all $ps > .133$.

The same repeated measures ANOVA was computed for HEOG amplitudes in the N2pc epoch of 240–280 msec. There was only a significant effect of Expression of Looming Face, $F(1, 14) = 4.70$, $p = .048$, $\eta_p^2 = .25$, with no other significant main effects or interactions, $Fs < 3.86$, all $ps > .069$. However, follow up paired t -tests revealed that this effect was due to an increased positivity for the inverted neutral looming face ($M = .29$, $SEM = .37$) compared to the inverted fearful looming face ($M = -.68$, $SEM = .31$), $t(14) = -3.03$, $p = .009$, $dz = -.78$. There were no other significant differences in the HEOG amplitude across any of the combinations, all $ts < 1.88$, all $ps > .082$.

While there was one significant effect, this was only for the inverted faces, where we did not observe any significant effects in the N2pc amplitudes based on the average of PO7/PO8, P7/P8, PO3/PO4, and O1/O2. Therefore, across both

epochs, horizontal eye movements likely did not influence the data.

2.3. Discussion

Experiment 1 revealed the presence of a significant l-N170 for looming faces underscoring the importance of movements of approach in visual processing. With respect to our hypothesis, although no significant interaction was observed between looming and expression, subsequent planned comparisons revealed a significantly more negative l-N170 for upright looming fearful faces compared to neutral faces and inverted stimuli. This result suggests that beyond the actual imperative processing of any approaching stimulus, the looming of a fearful face may be additionally prioritised. Moreover, the fact that this was not observed for fearful inverted faces showed that prioritised processing was not due to the low-level features of fearful faces, but rather to their emotional contents. It should be noted however that our comparisons focused only on the (lateralised) differences across emotions, due to our specific hypotheses. However, the N170 showed a bilateral negativity indicating the presence of a contralateral N170 component (or l-N170) for all faces.

Of note, the l-N170 was not enhanced for inverted faces. This finding was unexpected and is most likely due to the differences in procedure in our investigation. Reports describing an increased N170 for inverted faces have presented static faces (e.g., Anaki, Zion-Golumbic, & Bentin, 2007; Boehm, Dering, & Thierry, 2011; Caharel, Fiori, Bernard, Lalonde, & Rebai, 2006; de Haan, Pascalis, & Johnson, 2002; Eimer, 2000b; Itier & Taylor, 2004; Jacques & Rossion, 2007; Marzi & Viggiano, 2007; Righart & de Gelder, 2006), while our current study presented stimuli that were in motion throughout their period of presentation. Motion may have produced ERP modulations that counteracted this effect in way that remain to be determined. Such modulations may arise for different reasons. For example, it has been found that the location of fixation on upright and inverted faces modulate the N170 amplitudes and latencies to face inversion in a differential way (de Lissa et al., 2014). Similarly, attention also influences the N170 and l-N170 responses to upright and inverted faces along both amplitudes and latencies (Eimer, 2000b; Feng, Martinez, Pitts, Luo, & Hillyard, 2012). We suspect that the absence of an N170 inversion effect may therefore be the result of our experimental procedure (looming/receding motion; bilateral presentation of irrelevant faces), although additional studies are warranted to confirm this.

Regarding the N2pc, we observed an interaction between looming motion and orientation, reflecting first and foremost attentional capture by upright looming faces. Although emotional expression did not reach significance in the omnibus analysis of variance, the experimental question was specifically addressed using two-by-two comparisons. These revealed a larger N2pc for fearful upright looming faces, compared to the other conditions, underscoring a role of emotional expression in the attentional response. These observations are broadly in line with the previous findings of Eimer and Kiss (2007) showing that attentional attraction is

increased for fearful faces. Our current findings suggest that the effect may be further heightened by an approaching movement, although this interpretation should be considered with caution due to the absence of a statistically significant interaction of these factors. Nevertheless, attention appears to be enhanced by stimuli that are threatening and that approach the viewer. This interpretation also supports studies that reveal increased brain activation in response to threatening stimuli which enter a viewer's personal space (Mobbs et al., 2010) and provides the first evidence that a corresponding effect is reflected by larger N2pc amplitude.

However, while the results provide good evidence that a looming threatening stimulus is preferentially attended, it is still questionable whether this effect can be attributed to the stimulus entering peripersonal space or being perceived as closer to the observer. In the current paradigm, we increased the stimulus size to mimic an approaching trajectory for the stimuli, which would ultimately lead to entry into peripersonal space. It is possible that the observed effects were due to the stimulus size and/or motion, rather than their perceived spatial position. Moreover, differences in the size of the stimuli at the end of their implied trajectory could potentially lead to differences in lateralisation of the ERP components. Consequently, to rule out this potential confounds, we carried out a second experiment with static stimuli, in which the retinal size of the faces was always kept constant, but the physical viewing distance was manipulated.

In Experiment 2, we used the same fearful and neutral faces, but with the faces being relevant themselves, and directly manipulated physical distance by varying the distance between the monitor and the participant. Consequently, the screen was placed either within or beyond peripersonal space, and the actual size of the stimuli was adjusted at each of the two distances to ensure that the retinal image size was identical across conditions.

3. Experiment 2

The second experiment examined whether the distance of the faces affected the electrophysiological markers of face processing (N170) and attention (N2pc). Fearful and neutral faces were presented bilaterally on a screen that was situated either 50 cm away (within reaching distance) or at 120 cm (beyond reaching distance). Contrary to experiment 1 where faces were entirely irrelevant to the task, experiment 2 required faces to be attended by asking them to compare the two stimuli for gender (i.e., whether both faces were the same gender or not), although emotion remained irrelevant in this case. This was carried out with the aim of enhancing the expected attentional attraction of emotional faces in near and far space, while keeping the facial expressions irrelevant.

Subsequently, the I-N170 and N2pc components were examined for the two emotional expressions at the two distances.

We hypothesised that if the fearful faces attract attention more efficiently in peripersonal space, we should observe an

increased N2pc in this condition, compared to the more distant viewing condition.

3.1. Methods

3.1.1. Participants

The sample size was determined using the effect size Cohen's d_z of .65, which was found in Experiment 1 for the significant N2pc towards the looming upright fearful face. A power analysis using G*Power (Faul et al., 2007) was conducted with the following parameters: effect size (Cohen's d_z) of .65, alpha at .005 and power .90 this revealed a sample size of 27 participants were required.

Thirty participants from the University of Queensland took part in Experiment. Participants had no self-reported neurological conditions, had normal or corrected-to-normal vision and were compensated with AU\$40 for their time. Of the 30 participants, 16 were female, and 14 males, with a mean age of 24.43 (age range: 18–64 years, $SD = 9.66$) and two participants were left-handed.

3.1.2. Apparatus

EEG data were recorded using a 64-channel BrainProducts EEG system (Gilching, Germany) with a BrainAmp DC amplifier connected to a personal computer. The personal computer contained an Intel Core i5-4790 CPU 3.50 GHz processor, equipped with an Intel(R) HD Graphics 4600 card and was controlled by Psychopy software (Peirce et al., 2019). A standard USB mouse and keyboard were used to collect manual responses. The stimuli were displayed on a 19" colour LCD monitor with a resolution of 1280×1024 pixels and a refresh rate of 60 Hz. The viewing distance was approximately 50 cm in the close condition, while in the away condition the viewing distance was increased to approximately 120 cm.

3.1.3. Stimuli

In Experiment 2, we used the same upright fearful and neutral faces as in Experiment 1, presented against a grey background (RGB: 125, 125, 125; see Fig. 3). The size of the stimuli was

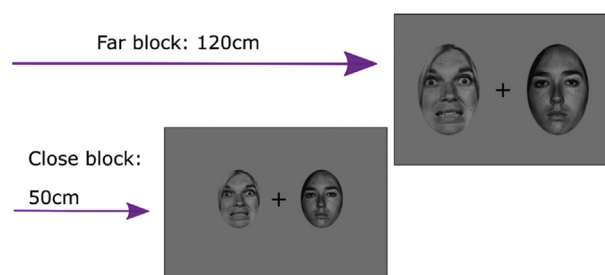


Fig. 3 – Experiment 2. Each trial started with a variable inter-trial interval between 800 and 1,500 msec. Faces were then presented for 100 msec and the screen was left blank until participants entered a response. Participants were asked to report if the faces were of the same gender or not using the arrow keys. Stimuli were presented in blocks at either close or far physical distances (with the order of conditions counterbalanced across participants).

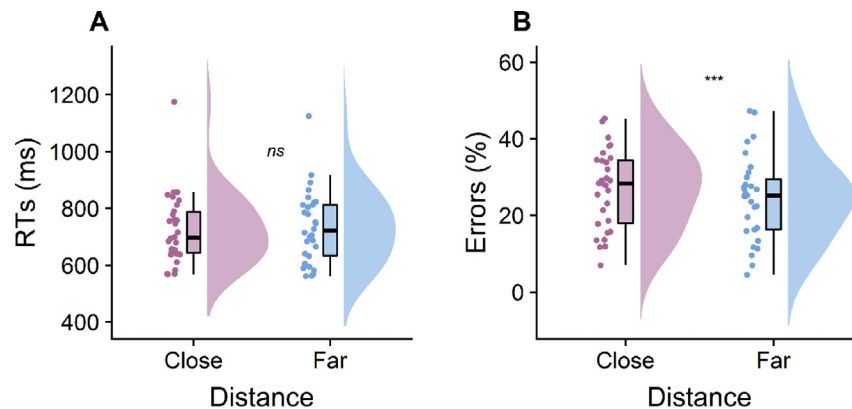


Fig. 4 – Raincloud plots for RTs and error rates (%). A) Mean RTs for faces appearing at either a close (i.e., 50 cm) or far (120 cm) distance. There was no difference in RTs when responding to the gender of the faces at either a close or far distance. B) Mean error rates (%) for faces appearing at a close (i.e., 50 cm) or far (120 cm) distance. Significantly more errors were made when faces were presented at a close distance compared to farther away. * $p < .05$; ** $p < .01$, *** $p < .001$, as per two-tailed t-test.

modified for near and far presentations such that the visual angle of the images were $2.6^\circ \times 3.6^\circ$ across both conditions (Eimer & Kiss, 2007). Faces were presented bilaterally on either side of a central fixation dot (2.06° from the fixation point to the inner edge of the image).

3.1.4. Design and procedure

Participants were instructed to keep their gaze on the fixation dot at the centre of the screen during the experiment. Their task was to respond as to whether the gender of the two faces was the same or not. They were required to press the left arrow key if both faces were of the same gender or the right arrow key if they were different.

On all trials, one face was fearful while the other was neutral. The gender of the face stimuli was controlled such that the combinations, male–male, female–female, male–female and female–male appeared an equal number of times. In addition, expression was counterbalanced so that fearful female faces appeared with neutral male faces as frequently as fearful male faces with neutral female faces, and similar for male–male and female–female pairings (whereby these combinations never showed the same individual). Moreover, the location of the images was counterbalanced, where half of the trials displayed a fearful expression on the left and half showed this expression on the right. This yielded a total of 144 combinations that were repeated three times in each block. Participants completed 4 blocks for the entire experiment (totaling 1,728 trials).

For 2 blocks, the monitor was situated at a viewing distance of 50 cm (near space), while for the other 2 blocks; the screen was viewed at 120 cm. The order of the blocks was far–near–near–far for half the participants and near–far–far–near for the other half.

Each trial started with a variable pre-trial interval of 800–1,500 msec, followed by the faces for 100 msec. A blank screen showing only the fixation point was then presented and remained on screen until participants entered a response.

Each participant started the experiment with 40 practice trials that contained feedback about the accuracy of the

response (same, different gender) that were not included in the analyses. The experiment took approximately 1 h to complete.

3.1.5. Data analysis

Data were analysed in the same way as in Experiment 1. Raincloud plots were created in R to illustrate the behavioural data (Allen, Poggiali, Whitaker, Marshall, & Kievit, 2019; R Core Team, 2016). For behavioural data, trials were excluded from further analysis when they contained fast (i.e., less than 200 msec) or slow responses (i.e., greater than 2,000 msec), leading to a loss 3.76% of trials. For the EEG data, trials were excluded from analysis when responses were anticipatory or delayed (3.45% of trials lost), when they contained blinks (10.84% trials lost) or horizontal eye movements (12.59% of trials lost). Overall, 73.13% (37,908 trials in total and on average there were 316 trials per condition) of the trials remained for EEG data analysis across all subjects (each participant retained on average 1,263.60 trials).

3.1.6. EEG data recording and analysis

The continuous EEG was recorded from the traditional 64-scalp electrode setup in an elastic cap. Impedances were kept below 5 k Ω . Data was sampled at a rate of 500 Hz, with DC mode as the low cut-off and on-line filtered with a high cut-off filter of 40 Hz. EEG data were analysed with the Brain Vision Analyzer 2.0 (Brain Products, Gilching, Germany). All electrodes were re-referenced to the average of all scalp electrodes (same electrodes as in Experiment 1).

Trials that contained artefacts (i.e., blinks exceeding $\pm 60 \mu\text{V}$ in the Fpz channel; horizontal eye movements exceeding $\pm 30 \mu\text{V}$ in the HEOG; muscular movements exceeding $\pm 80 \mu\text{V}$ in all other channels) were excluded from EEG analysis (Eimer & Kiss, 2007; Martin & Becker, 2018). The remaining data were segmented into epochs ranging from 100 msec prior to stimulus onset, to 400 msec post stimulus onset, relative to a 100 msec pre-stimulus baseline. ERP waveforms were computed for the fearful face (i.e., the waveforms reflect contralateral and

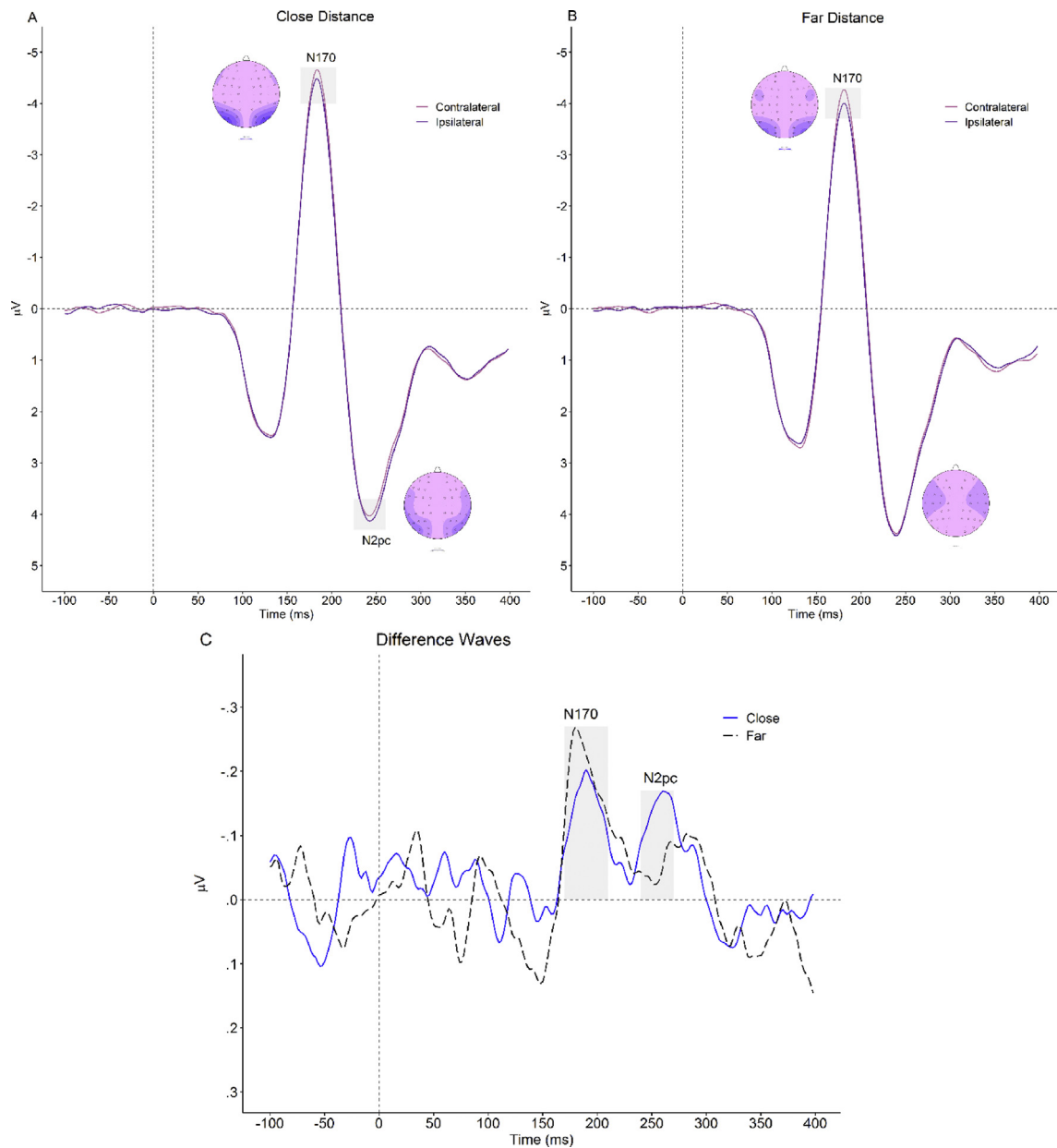


Fig. 5 – ERPs averaged over electrode sites PO7/PO8, P7/P8, PO3/PO4, and O1/O2 with contralateral (solid pink line) and ipsilateral (solid purple line) in reference to the fearful face. Topographic maps highlight the amplitude difference between contralateral minus ipsilateral, with a scale of .5 μV to $-5 \mu V$. **A)** At the close distance, there was a significant l-N170 in the first epoch (170–210 msec) and an N2pc in the second epoch (240–280 msec). **B)** At the far distance, there was a significant l-N170 component only. **C)** Difference waves for close and far distances, showed no significant difference across the different distances for the l-N170, however a significantly larger N2pc for the close faces.

ipsilateral responses in reference to the fearful face) at both distances (i.e., 50 cm and 120 cm). Mean l-N170 amplitudes were computed using the epoch of 170–210 msec post-stimulus (where the l-N170 had its peak), and the mean amplitudes for the N2pc were computed in the 240–280 msec post-stimulus epoch (as in Experiment 1),

from the average of the same four electrode pairs as in Experiment 1: PO7/PO8, P7/P8, PO3/PO4 and O1/O2²

3.2. Results

3.2.1. Behavioural results

Paired t-tests revealed that response times (RTs) did not differ significantly between the close and far distance conditions, $t(29) = -1.19$, $p = .243$ (see Fig. 4A). An analysis of the mean errors showed that there were significantly more errors made in identifying the gender of the faces at a close distance,

² Channels PO7 and PO8 were also analysed in isolation at the point of maximal effect within the same epochs and revealed the same results as with the 4 electrode pairs.

compared to the farther distance, $t(29) = 3.97, p < .001, dz = .73$ (see Fig. 4B). Thus, whilst RTs were not influenced by distance, error rates were affected with more errors made when faces appeared closer, within peripersonal space.

3.2.2. ERPs towards fearful faces

3.2.2.1. MEAN L-N170 AMPLITUDE. A 2 (Distance: Close, Far) \times 2 (Fear-lateralization: Contralateral, Ipsilateral) repeated measures ANOVA over the mean amplitudes for the l-N170 to the fearful face in the first epoch of 170–210 msec, showed a significant main effect of Distance, $F(1, 29) = 11.94, p = .002, \eta_p^2 = .29$, with a greater l-N170 for close ($M = -3.19, SEM = .79$), compared to far faces ($M = -2.61, SEM = .82$), and Fear-lateralization, $F(1, 29) = 13.62, p < .001, \eta_p^2 = .32$, with a greater negativity for the electrodes contralateral ($M = -2.99, SEM = .81$) to the fearful face, compared to ipsilateral electrodes ($M = -2.81, SEM = .79$; see Fig. 5). However, there was no significant interaction between the two variables, $F < 1, p > .420$.

Paired t-tests showed a reliable l-N170 for the fearful faces (i.e., greater contralateral negativity for the fearful face compared to the neutral face), both at a close distance, $t(29) = -3.30, p = .003, dz = .60$ (see Fig. 5A), and at the far distance, $t(29) = -3.08, p = .004, dz = .56$ (see Fig. 5B). A comparison of the l-N170 enhancement for fearful faces in near and far presentations was performed by computing difference waves (contralateral fearful face minus ipsilateral neutral face) and comparing these waves across spatial conditions. No significant differences in negativity was observed ($t < 1, p = .421$ - see Fig. 5C), revealing no interaction between emotion and distance at the level of the l-N170.

3.2.2.2. MEAN N2PC AMPLITUDE. A 2 (Distance: Close, Far) \times 2 (Fear-lateralization: Contralateral, Ipsilateral) repeated measures ANOVA comparing the mean N2pc amplitudes in the later epoch of 240–280 msec, revealed no significant main effects or interaction, all $F_s < 3.82$, all $p_s > .060$.

Paired t-tests showed a significant N2pc towards the fearful face (i.e., greater negativity towards the contralateral fearful face) at a close distance, $t(29) = -3.08, p = .004, dz = .56$ (see Fig. 5A), but no significant effect at the far distance, $t < 1, p = .378$ (see Fig. 5B). No difference in negativity was observed in the difference waves comparing close and far distance, $t < 1.41, p = .173$.

3.2.2.3. HORIZONTAL EYE MOVEMENTS (HEOG). To measure if any horizontal eye movements differed across conditions, a slightly different analysis was conducted, with a 2 (Distance: Close, Far) \times 2 (Side of Fearful Face: Left, Right) repeated measures ANOVA over the mean amplitudes for the HEOG channel in the first epoch for the N170 of 170–210 msec. This showed no significant main effects or interactions, all $F_s < 1.14$, all $p_s > .295$.

To compare the two main conditions, HEOG amplitudes were collapsed over Left and Right fearful faces, resulting in separate mean HEOG amplitudes for the Close vs Far conditions. Paired t-tests revealed no significant differences in the HEOG amplitude across close or far conditions, $t = .44, p = .661$.

The same repeated measures ANOVA was computed for HEOG amplitudes in the N2pc epoch of 240–280 msec. A

significant interaction was observed between Distance and Side of Fearful Face, $F(1, 29) = 6.01, p = .020, \eta_p^2 = .17$. There were no significant main effects, all $F_s < 2.81$, all $p_s > .105$. Paired t-tests revealed that for the Close condition, there was significantly more positivity when the fearful face appeared on the right of the screen ($M = .50, SEM = .19$), compared to the left side of the screen ($M = .16, SEM = .20$), $t(29) = -3.05, p = .005, dz = -.56$. However, for the Far condition there was no difference in HEOG amplitude toward the fearful face regardless of which side of the fixation point the face was located, $t = .02, p = .984$.

To compare the main two conditions, HEOG amplitudes were collapsed over Left and Right fearful faces, resulting in mean HEOG amplitudes for the Close vs Far conditions. Paired t-tests found that there were no significant differences in the HEOG amplitude for close versus far condition, $t = .91, p = .373$.

Overall, there was potentially a difference in eye movements depending on whether the fearful face was presented on the right side of the screen compared to the left side. However, due to counterbalancing the position of the fearful face, this was unlikely to influence the N2pc in the Close condition.

3.3. Discussion

Experiment 2 indicated that viewing distance can modulate attentional capture by fearful faces independently of the actual retinal size. The l-N170 component was present at both distances, but more marked for faces that were in near than in far space. Moreover, fearful expression produced a greater negativity than neutral expressions, while no interaction was found with distance. By contrast, although the N2pc did not yield any significant effects in the omnibus analysis of variance, a specific comparison of this component in near and far space revealed that it was enhanced for fearful faces presented at close distances, suggesting that attentional capture is potentially greater for fearful faces within peripersonal space. These results therefore appear to support the view that physical distance from fearful faces modulates the impact of threat-relevant stimuli.

A relatively high proportion of errors were observed in experiment 2, the reasons for which are unclear. Interestingly, significantly more errors were made in gender judgements when faces were presented in peripersonal space compared to extrapersonal space. This suggests that physical proximity interfered with the task. It is likely that the more efficient attentional capture of the fearful faces (evidenced by the N2pc) at a close distance may have made it more difficult to process the gender of the other, unattended face, leading to more errors in gender judgements in this condition. This may have been due to the fact that more processing resources were needed for the face on the other, unattended side to determine its gender, which diminished the l-N170 to the fearful face when it was presented in peripersonal space.

Taken together, the findings of the two experiments suggest that threat-relevant stimuli such as fearful expressions have a greater effect on attention when they appear in peripersonal space compared to extrapersonal space, and that this effect occurs both when perceived distance is represented by looming motion or by differences in physical

distance, independently of any change in the size of the retinal image.

4. General discussion

The two experiments carried out here aimed to determine whether attentional capture of fearful faces is modulated by viewing distance, such that emotional faces might attract attention more strongly when the stimuli are presented within peri-personal space (reaching distance) than when they are situated beyond, in extrapersonal space. To our knowledge, this is the first electrophysiological study to show such an effect, reflected in a larger N2pc to fearful faces in peripersonal space than in extra-personal space. While the omnibus statistical analyses did not reveal significant effects, our hypotheses were verified by subsequent planned *t* tests focussing on the specific questions addressed by our study.

The comparisons that were carried out to address specifically our experimental questions appear to indicate that early processing is enhanced for approaching fearful faces (increased N170 in experiment 1) and captures attention more strongly (increased N2pc in experiment 1), and that moreover, fearful faces presented within peripersonal space also give rise to enhanced attentional capture (N2pc in experiment 2). Interestingly, the paradigms used in the current experiments contained a face on either side which were either relevant (Experiment 2) or irrelevant to the task (Experiment 1). The effect observed on the N2pc for fearful faces thus does not appear to involve voluntary control. This is consistent with the idea that fearful faces attract attention automatically, independent of the task or goals of the observers (e.g., Eimer & Kiss, 2007).

4.1. Face processing and the N170

It is noteworthy that the l-N170 component was not modulated by physical distance when stimuli subtended the same retinal size but was enhanced by fearful expressions similarly at both distances. Here, our larger N170 response corroborates previous studies reporting an enhanced N170 for emotional faces, further supporting the growing body of evidence indicating an N170 modulation for facial expressions of fear (Batty & Taylor, 2003; Blau et al., 2007). Our findings suggest that fearful faces at any distance lead to automatic processing, presumably because it is evolutionarily important to prioritise the processing of fearful faces in the observer's field of view.

Remarkably, we found a significant l-N170 to approaching fearful faces but not to receding fearful faces. It is conceivable that retinal size may have interfered with the processing of the receding fearful face. Previous studies have reported an enhanced l-N170 or N170 for fearful faces even when they were masked and not detectable (i.e., when they were presented subliminally; Carlson & Reinke, 2010; Pegna, Landis, & Khateb, 2008). Nevertheless, the receding fearful faces in this study may have produced a significant loss in resolution such that processing was hindered. Alternatively, the decreasing size of the image may have weakened the N170 component

compared to the looming condition. Although these factors may have contributed to the effect of looming motion which emerged in the overall analysis, the subsequent planned comparison show that the effect is not present for inverted fearful faces, suggesting that an explanation purely in terms of low-level effects is unlikely.

4.2. Attentional capture and the N2pc

In addition to finding a robust N2pc in response to the fearful faces, the present experiments showed an enhanced N2pc to fearful faces in peripersonal space, both when the fearful face expanded, simulating approach, and when we directly manipulated the physical distance of the monitor. Together, these results establish that involuntary capture by emotional faces is reliably modulated by the distance to the observer. These findings support previous N2pc studies that also found an enhanced response to fearful faces (Eimer & Kiss, 2007; Holmes et al., 2005; Santesso et al., 2008). In Experiment 2, we did not find an N2pc at the far distance. This is surprising given the previous studies that reported an N2pc for emotional faces, where distance was not manipulated. However, in these experiments, screen distances were usually around 60–70 cm away from the participant (Holmes et al., 2005; Santesso et al., 2008), corresponding essentially to close space. It is therefore possible that the N2pc is attenuated in far space but that this effect has not been observed due to the habitual location of computer screens within (or close to) peripersonal space. This finding supports the view that the attentional effects of potentially threatening stimuli are modulated by the perceived distance to the stimuli, which presumably changes the relevance or threat potential.

This difference in close vs far space regarding attentional allocation is supported by previous neurophysiological studies that have demonstrated a dissimilar pattern of activation in different brain regions when spatial attention is deployed in near vs. far space. For instance, a number of studies have observed double dissociations in patients with unilateral spatial neglect, in whom near space or far space were selectively impaired (Berti & Frassinetti, 2000; Halligan & Marshall, 1991; Pegna et al., 2001; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998). These observations pointed to the involvement of different cortical networks in the representation of peripersonal and extrapersonal space, as well as the importance of possible actions in determining the boundaries of peripersonal space. Our study further supports the role of physical distance playing an important role in the allocation of attention.

In addition to the effects of distance, our study highlights the additional, interactive effect of fear/threat. In emotion research, the distance of a fear-relevant stimulus to the viewer has also been shown to modulate activity in the amygdala, which responds specifically to fear-relevant or potentially threatening stimuli. For instance, as noted above, Mobbs et al. (2010) found that fear-related areas of the brain were enhanced when a spider was perceived to be located close to the participant than when it is farther away. Although the role of the amygdala cannot be established on the basis of our current findings, it is possible that this structure may

contribute to the heightened response to looming, fearful stimuli. Brain imaging investigations would be necessary however to determine whether this is the case.

Interestingly, these results support previous studies that had found looming motion to attract attention. In an ERP study by Pegna, Gehring, Meyer, and Del Zotto (2015), a light-point walker was presented walking in the lateral plane, from left to right, or right to left, or still was seen walking towards (expansion) or away (contraction) from the viewer. Radial motion was seen to modulate the P1 component, again demonstrating that looming vs. receding motion may trigger different early perceptual processes. It therefore emerges that looming motion of potentially threatening stimuli is likely prioritised and leads to rapid attentional capture.

4.3. Conclusion

Our current findings demonstrate that attention prioritises emotional faces that are approaching, or are situated close to the viewer, demonstrating that threat and peripersonal space interact to produce attentional capture. We would surmise that this enhancement may be the result of differential activation of neural networks for near and far space, with the former network possibly involving participation of the amygdala. However, further evidence is required to establish with more certainty the cortical structures engaged, and future studies may include virtual reality immersions with EEG/ERP to allow for a better simulation of the different spatial compartments.

CRedit author statement

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Open practices

The study in this article earned Open Materials and Open Data badges for transparent practices. Materials and data for the study are available at https://osf.io/zg89x/?view_only=e7e32fca399046fbbbb8965d0bcf1267.

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