Fearful face scrambles increase early visual sensory processing in the absence of face information

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Abstract
Emotional facial expressions elicit distinct increased early electrophysiological responses. Many studies report even emotional modulations of very early sensory processing at about 80 and 100 ms after stimulus presentation, indexed by the P1. These early effects are often interpreted to index differential responses to biologically relevant expressions. Since specific spatial frequencies differ between fearful and neutral expressions, it has recently been suggested that these early modulations are substantially driven by such low-level visual differences. However, it remains unclear whether similar P1 effects are also observed in experiments in which no recognizable face information is presented at all. This study investigated this question and explored also whether any effects depend on colour information and attentional conditions. Participants (\(N = 20\)) performed a continuous perceptual task of low or high difficulty and were presented with task-irrelevant black/white and colour images of fearful and neutral faces, rendered unrecognizable by doing Fourier phase transformation. ERP findings revealed increased P1 amplitudes for fearful scrambles regardless of experimental conditions. Taken together, our findings show early emotional effects in the absence of any facial expression. Specific low-level frequency information seems to increase P1 amplitudes which thus might have implications for the interpretation of very early sensory emotional expression effects.

Keywords
EEG/ERP, face-scrambles, fearful expressions, low-level emotion effects, P1

1 | INTRODUCTION

A differential processing of face and emotion information occurs rapidly, as evident by modulations of early event-related potentials (ERPs), which represent distinct stages of the face and emotional expression processing. One of the earliest visual sensory potentials is the P1 component. The P1 is a positive amplitude deflection over parieto-occipital sensors typically peaking between 80 and 100 ms after stimulus onset. It is thought to reflect early stages of stimulus detection and discrimination (Hopfinger & Mangun, 1998; Luck & Hillyard, 1994; Vogel & Luck, 2000), being enlarged for faces compared to objects (Allison et al., 1999; Bentin et al., 1996; Neumann...
et al., 2011; Thierry et al., 2007). Nevertheless, some studies show no P1 differences between faces and objects (Ganis et al., 2012; Schendan & Ganis, 2013), and some findings suggested that these P1 differences are based on low-level information, being similar for faces and non-recognizable scrambled versions (Rossion & Caharel, 2011; but see also Bieniek et al., 2012). In contrast to the P1, reliable face-object differences start with the subsequent N170 (Rousselet et al., 2008).

Regarding emotional expression effects on the P1, increased amplitudes have been reported for fearful compared to neutral expressions (e.g. see Mühlberger et al., 2009; Santos et al., 2008; Li et al., 2018; Müller-Bardorff et al., 2018), even though emotion effects seem to be variable (for a recent review, see Schindler & Bublatzky, 2020). In a recent study, we observed increased P1 amplitudes for emotional compared to neutral faces, but we observed similar effects also for scrambles of emotional compared to neutral faces (Schindler et al., 2020). This suggests that emotional P1 modulations are at least partially face-unspecific responses to low-level visual information. This low-level information might be related to differences in the spatial frequency spectrum that remain after scrambling. Emotion-specific frequency information of fearful faces has been found to influence P1 modulations, showing attenuated fearful-neutral differences for the P1 when both expressions contained only neutral frequency spectra (Bruchmann et al., 2020). This would indicate that very early differences between fearful and neutral faces can be explained by a sensitivity of the visual system to specific amplitude information, rather than face-specific processing (see also Hedger et al., 2015).

However, in previous studies, a large number of trials, including the presentation of intact faces, were realized (>100 trials), and there might be associative learning of the intact emotional expression and its low-level information, transferring inherently face-specific emotion effects to their scrambled counterparts. For example increased fMRI responses in the lateral-occipitotemporal cortex to noise stimuli were found when participants expected to see faces (Smith et al., 2012). Furthermore, it remains unclear whether and how any P1 emotion effects in reaction to face scrambles that are presented in the complete absence of intact faces are influenced by additional factors such as attentional conditions and colour. Previous studies suggested a relative insensitivity of P1 emotional expression modulations by perceptual load difficulty or attentional condition (e.g., see Holmes et al., 2006; Rellecke et al., 2012; Schindler, Bruchmann, Gathmann, et al., 2020; Schindler et al., 2020), and that they are independent of colour information (Schindler et al., 2019). However, other studies reported colour effects on the P1 (Frühholz et al., 2009; Xia et al., 2018) and perceptual load effects on P1 fearful-neutral differences when perceptual load preceded face presentation (Schindler et al., 2020).

### Highlights
- Larger P1 amplitude for fearful compared to neutral scrambles
- No exposure to faces or fearful expression necessary
- Implications for the interpretation of P1 emotional expression effects

In this study, we systematically tested whether Fourier phase-scrambled versions of fearful and neutral faces modulate the P1 when only scrambles are presented. To investigate whether any ‘emotion’ P1 effects depend on colour information of scrambles and attentional conditions, participants were presented with task-irrelevant black/white and colour Fourier phase scrambles of fearful and neutral faces while performing a continuous perceptual load task.

## 2 Methods

### 2.1 Participants

Twenty-one participants were recruited at the University of Muenster. One participant was rejected due to problems with EEG recording, leading to a final sample size of 20 participants (8 males). Participants were 22.95 years on average (median = 22, Min = 19, Max = 34, SD = 4.3). They gave written informed consent, and received 10 Euros per hour and an additional performance-dependent bonus of up to 5 Euros for their participation. All participants had normal or corrected-to-normal vision, were right-handed, and had no history of neurological or psychiatric disorders. All procedures were following the Helsinki declaration (2008 amendment) and the research protocol has been cleared by the local ethics committee.

### 2.2 Stimuli

The original facial stimuli were taken from the Radboud Face Database (Langner et al., 2010), using 36 identities (18 males and 18 females), showing either fearful or neutral facial expressions. First, an oval aperture with Gaussian blurred edges was applied onto each face image, thus removing sharp boundaries between face and background. Images were then reduced to the smallest possible rectangle to minimize the contribution of non-facial features to the image’s spectrum. From this cut-out of the coloured fearful and neutral expressions, Fourier phase-scrambled...
versions were created (see Figure 1), which retained the contrast per orientation and spatial frequency. At the same time, this procedure removes systematic luminance differences between fearful and neutral faces which resulted from systematic relationships between different phases. Fourier phase-scrambling was achieved by calculating the Fast Fourier Transform (FFT) of each image, separating amplitude and phase spectra, and then replacing the original phase spectrum with the phase spectrum of a random noise image of equal size for all but the DC component. Each image's phase spectrum resulted from a different randomized noise image, however, in the case of coloured images, the same random phase spectrum was applied to the red, green, and blue layers of each image. From these coloured face-scrambles, black-and-white versions were created by averaging RGB values of each pixel. The product of this procedure is a rectangular image with sharp luminance edges if placed on a homogenous background. To prevent sharp luminance edges, we applied the same oval aperture as described above for a second time. It should be noted that this step alters the original frequency spectrum as the contrast in some parts of the image is artificially reduced to zero. However, the reduction is non-systematic concerning the specific orientation- and spatial frequency components and thus independent of our experimental manipulation. Also, coloured scrambles and their corresponding black-and-white versions do not necessarily share the same average luminance. This difference, however, does not affect the comparison of fearful and neutral faces (see Figure 2). Another caveat pertains to the removal of systematic relationships between different phases in coloured images, as this potentially affects the resulting colour mixtures. Each stimulus had a width of

**FIGURE 1** Illustration of image manipulation procedure. FFT refers to Fast Fourier Transform. Ampl and Ph refer to amplitude and phase spectra, respectively, and are depicted for the red (R), green (G) and blue (B) colour channel.
4.5 degrees of visual angle (deg) and a height of 7.5 deg. Stimulus examples are provided in Figure 2.

2.3 Procedure

Participants first responded to a demographic questionnaire and completed a practice task to familiarize themselves with both perceptual load difficulty levels while being prepared for the EEG. Then the main experiment started, divided into eight blocks (four blocks for each perceptual load level). Participants were informed that ‘indistinct patterns’ would be presented which were task-irrelevant. Distracter scramble stimuli were presented in the middle of the screen for 50 ms, separated by an intertrial interval (ITI) ranging from 800 to 1,200 ms (see Figure 3). The stimuli chosen for the continuous task consisted of 12 red dots (RBG: [179,0,0], referred to as standard colour) distributed on three imaginary rings (largest 6.5°, middle 4.5°, smallest 2.5°). In every imaginary ring, four dots were spaced equidistantly (see Figure 3). The dots were smallest in on the innermost ring (0.32°) and larger in the middle ring (0.41°) and the outermost ring (0.52°). Throughout the experiment, the dots rotated along with the rings (with a delta angle of 1° per frame). The direction of rotation alternated between clockwise and counter-clockwise every 20 s (ranging between 15 and 25 s). On average, every 10 s (ranging between 5 and 15 s between two targets), one of the red dots changed its colour for 100 ms, whereas each dot was equally likely to change in its colour and this variation served as target. Participants were requested to respond by pressing the space key whenever they detected such a colour change as quickly as possible, as they were only rewarded for fast hits (<1,000 ms). This was a marked colour change (see Figure 3) to white (RGB: [255,255,255]) in the low perceptual load.
condition, whereas a less evident change occurred in the high perceptual load condition. In the practice blocks, participants were requested to detect five colour changes of low and high perceptual difficulty. This ensured that participants could perform both tasks and were sensitized for colour changes in both conditions. To ensure comparable performance for high versus low perceptual load across participants, the target colour was initially set to RGB [255,0,0] during the high perceptual load condition and adjusted online by reducing or increasing the RGB contrast relative to the standard colour. Three consecutive hits resulted in a contrast reduction by 30% (cut-off at RGB [180,0,0]) and three consecutive misses resulted in a contrast increase by 20% (cut-off at RGB [255,0,0]).

After each block, the experiment paused for at least 30 s to give the subjects a short rest break and they received feedback on their performance and the amount of money they won or lost in that specific block, and the total amount of money they earned so far. Participants could prolong these breaks as the experiment only restarted once they pressed the spacebar. In each block, on average 15 colour changes and 144 distracting stimuli occurred. In total, 1,152 distracters were presented in the experiment summing up to a total of 144 presentations for each of the eight conditions (load: low, high; modality: black/white scramble, colour scramble; emotion: fearful versus neutral).

Stimuli were presented on a Gamma-corrected display (NBC Multisync E231W 23") running at 60 Hz with a Michelson contrast of 0.9979 ($L_{\text{min}} = 0.35 \text{ cd/m}^2$; $L_{\text{max}} = 327.43 \text{ cd/m}^2$). The background was set to medium grey, corresponding to the average image luminance of 163.89 cd/m². Lookup-tables were created based on luminance measurements with a photometer (Datacolor Spyder 5 ELITE) to linearize the relationship between RGB value and luminance. Stimulus presentation was done using MATLAB Psychtoolbox.

### 2.4 | EEG recording and preprocessing

EEG signals were recorded continuously from 64 BioSemi active electrodes using Biosemi Actiview software (www.biosemi.com). Four additional electrodes measured horizontal and vertical eye-movements. These were placed at the outer canthi of the eyes and below and above the right eye. The recording sampling rate was 512 Hz. A Common Mode Sense (CMS) active electrode and a Driven Right Leg (DRL) passive electrode acted as a ground during recordings (for details see: www.biosemi.com/faq/cms&drl.html). Offline data were re-referenced to average reference. Data were then filtered with a causal high-pass forward filter of 0.01 (6 dB/oct). The use of causal high-pass filters is recommended since they do not smear effects back in time (see Acunzo et al., 2012; Rousselet, 2012). The LCD screen exhibited a delayed stimulus presentation of 15 ms (stimuli presented 15 ms after the trigger was sent), which was corrected during epoching. Further, a 40 Hz low-pass zero-phase filter (24 dB/oct) was used and filtered data were segmented in epochs from 100 ms before stimulus onset to 800 ms after stimulus presentation, using the 100 ms before stimulus onset for baseline-correction. Trials with rotation changes, responses, and trials with a colour change were excluded from ERP analyses. Eye movements were corrected using the automatic eye-artefact correction method implemented in BESA (Ille et al., 2002). The remaining artefacts were rejected based on an absolute threshold (<120 µV), signal gradient (<75 µV/∂T), and low signal (i.e. the $SD$ of the gradient, >0.01 µV/∂T). Bad EEG sensors were identified by visual inspection and interpolated using a spline interpolation procedure. On average, 1.95 electrodes ($SD = 1.54$) were interpolated. Including trials removed due to rotation changes, responses or targets, we kept 76% of all trials on average (see Table 1).

### 2.5 | Data analyses

For all analyses, Bayesian statistics were applied. The null hypothesis was specified as a point-null prior (i.e. standardized effect size $\delta = 0$) and defined the alternative hypothesis as a Jeffreys-Zellner-Siow (JZS) prior, that is a folded Cauchy

| | Fearful scrambles, $M$ (SD) | Min/Max | Neutral scrambles, $M$ (SD) | Min/Max |
|---|---|---|---|---|
| Low load black/white | 109.00 (4.46) | 100/117 | 108.50 (4.36) | 100/116 |
| Low load colour | 110.35 (5.68) | 97/125 | 108.40 (5.03) | 99/118 |
| High load black/white | 110.35 (6.23) | 103/122 | 114.85 (5.31) | 105/123 |
| High load colour | 110.30 (4.32) | 105/121 | 114.15 (4.72) | 103/122 |

Note: Standard deviation appears in parentheses behind means. Min, Minimum; Max, Maximum of kept trials per condition.
distribution centred around $\delta = 0$ with the scaling factor $r = 0.707$. This scaling factor assumes a roughly normal distribution. To assign verbal labels to the strength of evidence, we followed the taxonomy suggested by Jeffreys (1961), labelling Bayes Factors with a BF$_{10}$ of 1 as no evidence, BF$_{10}$ between 1 and 3 as anecdotal evidence, 3 and 10 as moderate evidence, 10 and 30 as strong evidence, 30 and 100 as very strong evidence and larger BFs as extreme evidence in favour of the alternative hypothesis. To obtain an appropriately interval-scaled measure of performance, we calculated the sensitivity index $d'$ (Macmillan & Creelman, 2005). Due to the continuous stimulus presentation, false alarms were evaluated relative to the number of non-target time intervals of the same length as the 1-s response interval for hits (Bendixen & Andersen, 2013). Reaction times were log-transformed and then averaged per subject. For reaction time (mean log(RT)) and $d'$, Bayesian paired $t$-tests were calculated (load: high load, low load). For EEG data, a two (emotion: fearful, neutral) by two (load: low load, high load) by two (scramble type: black/white scramble, colour scramble). Bayesian Repeated Measure ANOVA was set-up to investigate the effects of expression, load, scramble type, as well as their interaction for the P1 component. To identify the P1 time window and electrode clusters, ERPs collapsed across all conditions were inspected (see Luck & Gaspelin, 2017). For the P1, mean amplitudes were averaged from 80 to 130 ms over occipital sensors (P1 left: P9, P7, PO7, P5; right: P10, P8, PO8, P6).

3 | RESULTS

3.1 | Behavioural results

Behavioural results confirm a successful load manipulation by the experimental task. Participants responded on average faster under low load ($M_{\text{reaction time low load}} = 451$ ms, $SD = 58$ ms) compared to high load difficulty ($M_{\text{reaction time high load}} = 522$ ms, $SD = 43$ ms; $M_{\text{difference}} = 71$ ms, $SD = 37$ ms; Bayesian $t$-test results on mean log(RT): BF$_{10} = 210,939.53$, error $\% = 6.611e-10$). Furthermore, participants responded more accurately under low load compared to high load ($M_{\text{e}}$ low load = 4.69, $SD = 0.28$; $M_{\text{e}}$ high load = 2.91, $SD = 0.54$; $M_{\text{difference}} = 1.774$, $SD = 0.58$; BF$_{10} = 5.595e+8$, error $\% = 7.922e-14$).

3.2 | P1

The Bayesian Repeated Measure ANOVA shows the best model for separate main effects of emotion, scramble type, and perceptual load with no interaction terms (see Table 2, Figure 4). Regarding these main effects, the data show a higher P1 amplitude in fearful compared to neutral scrambles ($M_{\text{fearful}} = 2.62$, $SD = 1.55$; $M_{\text{neutral}} = 2.44$, $SD = 1.44$; $M_{\text{difference}} = 0.18$, $SD = 0.25$; emotion difference present in 15 of 20 participants), under low compared to high load ($M_{\text{low load}} = 2.64$, $SD = 1.57$; $M_{\text{high load}} = 2.42$, $SD = 1.42$; $M_{\text{difference}} = 0.22$, $SD = 0.25$; load difference present in 14 of 20), and for black/white compared to colour scrambles ($M_{\text{black/white}} = 2.67$, $SD = 1.55$; $M_{\text{colour}} = 2.39$, $SD = 1.43$; $M_{\text{difference}} = 0.28$, $SD = 0.25$; scramble difference present in 19 of 20).

4 | DISCUSSION

This study investigated the impact of low-level visual information on emotional expression effects on the P1 level in the absence of any facial information. We found evidence for an increase in P1 amplitudes for scrambles derived from fearful compared to those from neutral faces. The winning model suggested parallel effects of load, emotion and scramble type, not interacting with each other. Please note that interpreting the absence of interactions requires the assumption of a linear mapping, whereas scale transformations between dependent variables may be non-linear (see Wagenmakers et al., 2012).

These findings have implications for the interpretation of very early emotion effects, showing enlarged P1 responses to emotional expressions. While findings on P1 emotion effects are mixed (see Schindler & Bublatzky, 2020), and reported effect sizes are rather small, they have been found in several previous studies (e.g. see Li et al., 2018; Mühlberger et al., 2009; Santos et al., 2008), including some of our studies (Müller-Bardorff et al., 2018; Schindler, Bruchmann, Gathmann, et al., 2020). We recently observed P1 modulations in phase-scrambled versions of emotional faces compared to phase-scrambled neutral faces (Schindler, Bruchmann, Gathmann, et al., 2020). However, in the previous study, both faces and matched scrambles were shown. This left open the possibility that scrambles produced emotional effects due to—possibly implicit—learned associations between frequency spectra and emotional expressions during the experiment. This study, however, did not involve any recognizable images of faces, yet, reliably reproduced P1 effects. This suggests that low-level information in the form of amplitude differences in the Fourier spectra contributes to these early amplifications (Schindler, Bruchmann, Gathmann, et al., 2020).

This does not imply that emotional P1 modulations are insensitive to phase-information because we did not vary phase coherence. In doing so, Bieniek et al. (2012) showed that phase information does not affect P1 amplitudes, whereas it does affect N170 amplitudes. They further reported inconsistent and small Fourier amplitude effects in the P1 time window, which corresponds to the small effect size we observed. Since previously reported P1 differences between
emotional expressions have also been small (Schindler & Bublatzky, 2020), we conclude that our current finding of face-unspecific P1 emotion effects provides additional evidence that low-level differences between fearful and neutral expressions explain such early modulations to a large extent. This hypothesis is supported by the fact that replacing emotion-specific frequencies in fearful faces with neutral spectra reduces P1 effects for fearful compared to neutral expressions (Bruchmann et al., 2020). However, it remains an open question whether this shows sensitivity to the physical features of fearful faces as a result of evolutionary processes (Bruchmann et al., 2020; see also Hedger et al., 2015).

In this vein, it is also relevant which low-level features drive the effects. While phase scrambling preserves the amplitude spectrum of the original images, it alters image characteristics that depend on the correlations of phases across frequencies (phase coherence; Thomson, 1999). The most prominent effect of this procedure is the removal of local edges and thus of figural information, that is meaning (see Figure 2b). It also has some effect on the distribution of colour intensity or brightness. However, this effect does not introduce differences between scrambles of different emotional categories but removes them (see Figure 2a). Thus, although the eye white is an important signal in the processing of fearful faces

| Models | P(M) | P(M|data) | BF_M | BF_10 | Error % |
|--------|------|----------|------|-------|---------|
| load + scramble type + emotion | 0.053 | 0.370 | 10.564 | 1.000 |
| load + scramble type + emotion + load * emotion | 0.053 | 0.231 | 5.418 | 0.626 | 6.332 |
| load + scramble type + emotion + load * scramble type | 0.053 | 0.108 | 2.185 | 0.293 | 4.014 |
| load + scramble type + emotion + scramble type * emotion | 0.053 | 0.092 | 1.820 | 0.248 | 4.958 |
| load + scramble type + emotion + load * scramble type + load * emotion | 0.053 | 0.066 | 1.268 | 0.178 | 4.230 |
| load + scramble type + emotion + load * emotion + scramble type * emotion | 0.053 | 0.058 | 1.115 | 0.158 | 6.389 |
| load + scramble type + emotion + load * scramble type + scramble type * emotion | 0.053 | 0.030 | 0.558 | 0.081 | 9.866 |
| load + scramble type + emotion + load * scramble type + scramble type * emotion + emotion | 0.053 | 0.017 | 0.319 | 0.047 | 4.894 |
| load + scramble type + emotion + load * scramble type + load * emotion + scramble type * emotion + load * scramble type * emotion | 0.053 | 0.012 | 0.223 | 0.033 | 19.926 |
| load + scramble type | 0.053 | 0.011 | 0.191 | 0.028 | 3.730 |
| load + scramble type + load * scramble type | 0.053 | 0.003 | 0.058 | 0.009 | 4.487 |
| scramble type + emotion | 0.053 | <0.001 | 0.015 | 0.002 | 3.847 |
| scramble type + emotion + scramble type * emotion | 0.053 | <0.001 | 0.004 | <0.001 | 5.484 |
| scramble type | 0.053 | <0.001 | <0.001 | <0.001 | 3.569 |
| load + emotion | 0.053 | <0.001 | <0.001 | <0.001 | 4.199 |
| load + emotion + load * emotion | 0.053 | <0.001 | <0.001 | <0.001 | 8.687 |
| load | 0.053 | <0.001 | <0.001 | <0.001 | 4.699 |
| emotion | 0.053 | <0.001 | <0.001 | <0.001 | 5.509 |
| Null model (incl. subject) | 0.053 | <0.001 | <0.001 | <0.001 | 3.426 |

Note: All models include subject.
our results indicate that it may not be the maximum whiteness that drives this effect, at least not for the P1. For face-object differences, and especially for the later occurring N170, phase coherence and not amplitude information seem to be most relevant (see Bieniek et al., 2012; Rousselet et al., 2011; for emotion-specific frequencies, see Bruchmann et al., 2020).

4.1 Limitations and future directions

In this study, we showed that Fourier phase-scrambled versions of fearful and neutral faces elicit different P1 amplitudes. This procedure does not allow to quantify the exact contribution of the amplitudes spectrum and it does also not test the contribution of the phase spectrum. The
parametric variation of both spectra has been successfully applied to categorically (i.e. face versus object) different stimuli (Bieniek et al., 2012) and could provide more detailed insights if applied to faces of different emotional categories in future studies. Phase scrambling in coloured images may have an impact on the perceived colour scheme of the image (see Figure 1c). Since we did not observe interactions of emotion and colour scheme here or in previous studies (Schindler et al., 2019), the use of coloured scrambles appears unnecessary in future studies. Furthermore, our winning model proposed additive main effects of load, emotion and scramble type. However, the second-best model included the interaction of load and emotion. Future studies with larger statistical power are needed to explore such a possible load by emotion interaction for the P1. Finally, whereas FFT scrambles are a good first approximation to how the early visual system decomposes its input, a closer resemblance of this process may be offered by 2D wavelet decomposition. Since wavelets are applied locally rather than to the whole image at once, this procedure may also reveal whether phase or amplitude effects are restricted to or differ between specific regions of the human face.

5 | CONCLUSIONS

This study indicates that low-level amplitude information is sufficient to elicit early differential P1 modulations. This has strong implications for the interpretation of P1 emotion effects when using face stimuli. It remains to be investigated in future studies whether these low-level P1 effects have an evolutionary relevance associated with specific visual features or whether they represent a meaningless response to low-level properties of images.

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CONFLICTS OF INTEREST

The authors declare that they had no conflict of interest with respect to their authorship or the publication of this article.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

All raw data, results, paradigm and participant information can be retrieved in the open science framework project (https://doi.org/10.17605/OSF.IO/8C6QH).

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