Saccadic eye movements are deployed faster for salient facial stimuli, but are relatively indifferent to their emotional content

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Abstract

The present study explores the threat bias for fearful facial expressions using saccadic latency, with a particular focus on the role of low-level facial information, including spatial frequency and contrast. In a simple localisation task, participants were presented with spatially-filtered versions of neutral, fearful, angry and happy faces. Together, our findings show that saccadic responses are not biased toward fearful expressions compared to neutral, angry or happy counterparts, regardless of their spatial frequency content. Saccadic response times are, however, significantly influenced by the spatial frequency and contrast of facial stimuli. We discuss the implications of these findings for the threat bias literature, and the extent to which image processing can be expected to influence behavioural responses to socially-relevant facial stimuli.

Keywords: facial expression ; threat bias ; emotion ; saccadic latency ; spatial frequency ; contrast ; eye movements ; reaction time

Introduction

According to the threat bias theory, visual information indicative of environmental threat receives prioritised access to visual processing [1,2,3]. The evolutionary role of this prioritisation is to capture attention and facilitate its redirection towards the source of threat. Fearful faces are considered to play a unique role in this threat-avoidance system [1,2,4]. However, biases for responding to fearful facial expressions have been explored using a great number of paradigms, with mixed results. Studies of attentional cueing have addressed the distinct processes of the capture of attention by fearful faces, and the subsequent disengagement of attention from these stimuli. These results have shown both attentional capture and delayed disengagement by fearful faces [5,6], attentional capture only [7,3,8], or a complete absence of these effects [8,9,10 11]. Simple localisation tasks have shown that response times to detect fear expressions can be faster compared to neutral faces [12,13], or no different [14,15]. Some studies have shown detection advantages for fear expressions masked by continuous flash suppression, backward-masking and sandwich-masking techniques [16,17,18], while others have not [8,19].

Threatening stimuli cover a diverse range of hazards, and have been defined broadly as stimuli that are predictive of adverse effects [17]. These include stimuli that may be directly threatening in themselves, such as angry faces, and also those that are indirectly indicative of threat elsewhere in the environment, such as fearful faces [20]. In the latter case, any enhanced processing of fearful faces would be expected to serve the subsequent processing of the source of the threat. This has been proposed to occur through a number of effects, for example improved contrast sensitivity [21] or visual search efficiency [22], or faster orienting to the direction of gaze of fearful faces [23,24,25,26,27,28,29]. It is not a priori clear whether we would expect a threat bias in orienting to faces to enhance performance for direct threats, indirect threats, or both. However, in a meta-analysis of empirical studies, the strongest and most robust effect was found for fearful faces, but overall the evidence for threat-sensitive visual processing outside of conscious awareness was weak [17]. It may be that paradigm-related differences can account for the mixed findings that have been reported.

Here, we focus on saccadic latency. This paradigm has been employed by a number of studies investigating the threat bias, on the basis that it provides a naturalistic and ecologically-valid measure of the bias for fearful facial expressions, that is relevant to attentional capture, rather than disengagement [6, 12, 13]. Within this paradigm, we further explore how stimulus properties such as contrast and spatial frequency content contribute to the variability in responses to different facial expressions.

Saccadic latency refers to the first orienting step-like eye movement(s) deployed towards a visual stimulus, and how quickly this occurs following stimulus onset [12]. A short time delay between the onset of a visual stimulus and the first saccade towards it is taken as an indicator that the stimulus receives preferential allocation of attentional and/or processing resources. Saccades can be explicitly directed towards a stimulus, or occur as reflexive responses to unexpected stimuli [3,30]. These responses are considered to be reliable measures of perceptual biases because they capture implicit and automatic behavioural responses in a way that mimics natural viewing.

Despite this, compared to the wider literature on biases for detecting and responding to fear expressions there are relatively few studies of saccadic latency [6,11,12,13,31]. The findings from these studies are not always consistent, and can be difficult to compare due to differences in the tasks used. For example, studies have assessed the speed of *categorisation* of fear expressions [12] versus simple *detection* of stimuli presented after them, such as in an attentional cueing task [6,11]. In an emotion-directed localisation task, observers were presented with two faces (neutral and fearful) on either side of the screen, and were directed to ‘look towards’ the location of either the fearful or the neutral face, in separate blocks of trials [12]. Bannerman et al. [12] showed faster saccadic initiation when looking towards briefly presented fearful expressions. In an adaptation of this design, Bannerman et al. [6] used an attentional cueing task, in which fearful and neutral faces were presented as cues to target locations, and observers were required to look towards the target. Saccadic responses were faster following fearful face cues. Using a similar attentional cueing design, however, Khalid et al. [11] did not find faster saccadic reaction times for fearful faces. In a free-viewing, or 'fast capture' task, observers were simply required to look toward the location of a face target [13]. Saccadic responses were faster for fearful compared with neutral faces, but did not differ between fearful and happy faces, when stimuli were low-pass filtered. Opposing findings, however, were observed in a study by Seitz et al. [31], that also employed a 'fast capture' task for neutral, angry, fearful and happy faces. Initial saccades towards the eyes (as opposed to mouth) were faster for fearful compared to happy faces, though notably response times did *not* differ between fear and angry or neutral counterparts [31].

Another factor to consider is the extent to which the threat bias might be driven by simple image properties. Low-level accounts of the bias for fearful expressions posit that it is the image properties of the stimuli, as opposed to their affective or social relevance [32,33,34], that are responsible for differences in processing. The role of spatial frequency is common in these discussions, where a distinction is made between the lower frequency ranges that convey crude and coarse representations of a face, and the higher frequency information that depicts fine-scale expression-related facial detail. This focus reflects the potential role of specialised threat-processing mechanisms, for example in the amygdala [35], which respond only to low spatial frequencies. Alternatively, biases may reflect non-specialised aspects of visual processing, for example the effects of the contrast sensitivity function [17]. Across various paradigms findings show inconclusive frequency-dependent effects [8]. Some studies have found biased saccadic responses to low-pass fear expressions, relative to both neutral and happy expressions [13]. Others have found biases only for high-pass fear expressions in detection tasks where faces are suppressed from conscious awareness [18,3], or in judgement tasks related to the perceived salience of faces [36]. These differences may reflect the different tasks used in these studies [18]. Systematic investigations of saccadic responses to spatially-filtered facial expressions are rare [13]. This is surprising given that effects of spatial filtering on orienting responses are theoretically compatible with low-level accounts of the fear bias in which the prioritisation of fear expressions operates via crude and unconscious processing pathways [2,13], functioning primarily to direct the observer towards the source of the threat. Given the known tuning of these mechanisms, and their proposed role in rapid detection of fear-related cues, spatial frequency would be expected to influence the operation of orienting behaviours such as saccadic responses. Differences in low-level image properties may also potentially contribute to the inconsistent effects found in studies which used different stimulus sets. For example, studies of saccadic responses have used stimuli from the Ekman and Friesen [6], NimStim [12,31], or KDEF [11,13, 31] data sets [35,37,38]. These low-level accounts of the threat bias, that it is driven by physical properties that are characteristic of fearful faces, contrasts with the higher-level accounts, in which the recognition and understanding of the facial expression play a role in its enhanced visual processing. These potential accounts can be distinguished by stimulus manipulations such as rotation and polarity inversion that disrupt recognition but do not alter the relevant low-level image properties [32].

It is also important to explore how image contrast could influence saccadic responses. Naturally-occurring differences in contrast and Fourier amplitude spectra have been measured between facial expressions. Photographs of fearful faces have been found to have a lower Root Mean Squared (RMS) contrast than neutral, angry and disgusted faces, driven by a lower amplitude of the high frequency components of fearful faces [36]. Normalising faces for RMS contrast removes naturally-occurring contrast differences between expressions and for fearful faces in particular this process can artificially boost the degree of contrast required for a fearful expression to *appear* the same as other faces [36,39]. This disproportionate effect of contrast normalisation on already relatively lower contrast fear expressions [36,39] is also influenced by spatial frequency filtering, such that high-pass stimuli, for example, require substantially higher contrast than their low-pass counterparts to appear the same as a reference image [36,40]. These effects were most pronounced for stimuli when matched for their RMS rather than Michelson contrast [36]. These differences in contrast and amplitude spectrum are important since saccadic responses are slower for low-contrast and high frequency stimuli [41].

In the present study, we measured saccadic responses to neutral, fearful, angry, and happy expressions when low-pass or high-pass filtered for spatial frequency, and when presented in their unfiltered, broadband state. Given that contrast normalisation affects expressions differently according to their spatial frequency content [36], we assessed saccadic responses for facial stimuli in three contrast conditions, when raw and not matched for contrast, when normalised for RMS contrast, and when psychophysically matched for their apparent contrast. If image salience, defined here as the effects of contrast normalisation and spatial filtering, is important for eliciting saccadic eye movements, then we expect faster saccadic response times for physically salient stimuli, and a reduction of these effects when faces are made to be consistent at the perceptual level. The present study assessed the influence of stimulus stimulus frequency filtering and contrast normalisation on our initial eye movements towards the location of facial emotion.

Saccadic latencies were measured for photographs of faces that differed in their contrast (raw, RMS matched or perceptually matched), spatial-frequency filtering (original, low-pass, or high-pass filtered), format (original, or upside down and polarity reversed to impede the processing of their emotional content [32]), and expression (neutral, fearful, happy or angry).

Based on threat bias theory our primary predictions are that we would find shorter saccadic latencies for fearful faces. However, this may be mediated by the influence of other stimulus dimensions. For example, the threat bias is typically studied with stimuli that are matched for RMS contrast; however, if this is a robust, ecologically meaningful effect, then it should also be found for raw, unmanipulated stimuli. If the threat bias is driven by low spatial-frequency information [13,18] the predictions are that the bias should be absent for stimuli that have been high-pass filtered stimuli.

We also predicted that saccadic latencies may be influenced by the non-emotional properties of stimuli. For example, saccadic latencies would be expected to be longer for lower contrast [41] and high-pass filtered stimuli, which had a lower RMS contrast due to the amplitude spectra of portrait photographs [42]. Disrupting the recognition of the stimuli as faces by manipulating orientation and polarity may increase saccadic latency, or alternatively may decrease saccadic latency due to the effect of polarity reversal on the distribution of intensity levels [36].

Materials and methods

Participants

Twenty-three participants took part in the study (15 women), between 18 and 27 years of age, for all conditions apart from the RMS-matched, high-pass filtered stimuli. For that condition, a different group of twenty-one participants (12 women) completed the study as, due to a technical error, the stimuli were not fully matched for RMS contrast for the original group of participants. The sample size was chosen a priori to be broadly in line with that used in similar previous studies [6,11,12,13]. The University of Essex Ethics Committee approved the study and all participants gave written, informed consent.

Stimuli and apparatus

Stimuli were generated using MATLAB and the Psychophysics Toolbox extensions [43]. They were presented using a Dell E2417H monitor, viewed from a distance of 80 cm. The monitor screen was 48 cm wide and 27 cm tall, and had a resolution of 1920x1080 pixels and a refresh rate of 60 Hz. Each pixel subtended 1.2 arc min. The luminance response of the monitor was linearised using gamma-correction (Spyder 5 Elite, Datacolor). A chin-rest was used to maintain head position. Eye movements were recorded using an EyeLink 1000 eye-tracker (SR Research Ltd). Initial orienting saccades were recorded using the software's 'saccade start' function, defined as the point within a trial at which the saccade begins, measured in milliseconds. The sampling rate was 1000 Hz. Eye movements were recorded from the right eye.

Stimuli were greyscale, front-view face images of 10 individuals (5 women) extracted from the Karolinska Directed Emotional Faces (KDEF) set [35]. Models F03 ,F07, F16, F19, F29, M10, M20, M25, M29 and M31 were used. Stimuli were cropped to include internal features only. The rectangular cropping window was chosen by hand to ensure that it included all of the internal features for all of the models. Each face portrayed 1 of 4 expressions (fear, anger, happiness or neutral). Multiple emotional expressions were included to ensure that any effects of expression did not reflect a difference between neutral and emotional expressions, or between positively and negatively valenced emotions. Studies that only include fearful faces cannot draw conclusions about the perception of fear as such, because they fail to establish that any findings are not for example the result of any kind of emotional content relative to neutral faces, or a particular class of expressions, for example negatively versus positively valenced expressions. It is only by including a range of expressions, and showing that results for fearful faces are reliably and robustly different from those for multiple alternative facial expressions, that one can have any confidence that results really are because the faces are fearful. Spatially filtered versions of faces were created in MATLAB using a second-order Butterworth filter, with cut- off frequencies of $f < 1$ cpd for low-pass faces, and $f > 6$ cpd for high-pass faces. These cut-offs match those used in previous studies [18,36,44]. Each face subtended 5.4 degrees, such that the spatial amplitude spectrum of each face was either broadband, or was constrained to lower than 5 cycles per face-width (low-pass stimuli) or higher than 33 cycles per face-width (high-pass stimuli). Three contrast versions of faces were created: (1) 'raw' faces whose physical contrast was not adjusted in any way, such that any between-face differences were preserved, (2) RMS contrast-matched faces, and (3) psychophysically-matched faces, where each expression contained the contrast necessary to *appear* to have the same contrast as a 10% Michelson contrast standard. To create the final set of psychophysically-matched faces, we utilised data from a separate study in which participants (not associated with the present study) adjusted the physical contrast of facial stimuli - including the 10 KDEF faces used here- in order to perceptually match them for their apparent, perceived contrast [36].

Differences in physical contrast between the three stimulus conditions (raw, RMS-matched, and apparent-matched) are illustrated in Fig 1. It is important to note here that, due to the matching procedures used, raw contrast stimuli are overall higher in physical RMS contrast compared to both RMS- and apparent-matched stimuli (both $p<0.001$), but that the latter two conditions are not significantly different ($p=0.17$). We also know from previous findings that the raw stimuli contain naturally-occurring expression-related contrast differences [36]. Fear expressions are naturally *lower* in RMS contrast compared to neutral and angry counterparts, lower in RMS contrast compared to happy faces when low-pass filtered, and lower in RMS contrast than neutral, angry and happy expressions when high-pass filtered [36]. This naturally-occurring 'deficit' in contrast for fearful faces is shown in Figure 1, and is evident as spatial frequency is increased. On the other hand, in terms of the apparent, perceived contrast we also know that broadband fearful expressions appear higher in contrast than neutral and happy faces when RMS matched. When low-pass filtered, there is no difference in apparent contrast. When high-pass filtered, fearful faces appear higher in contrast than neutral and angry faces [36].

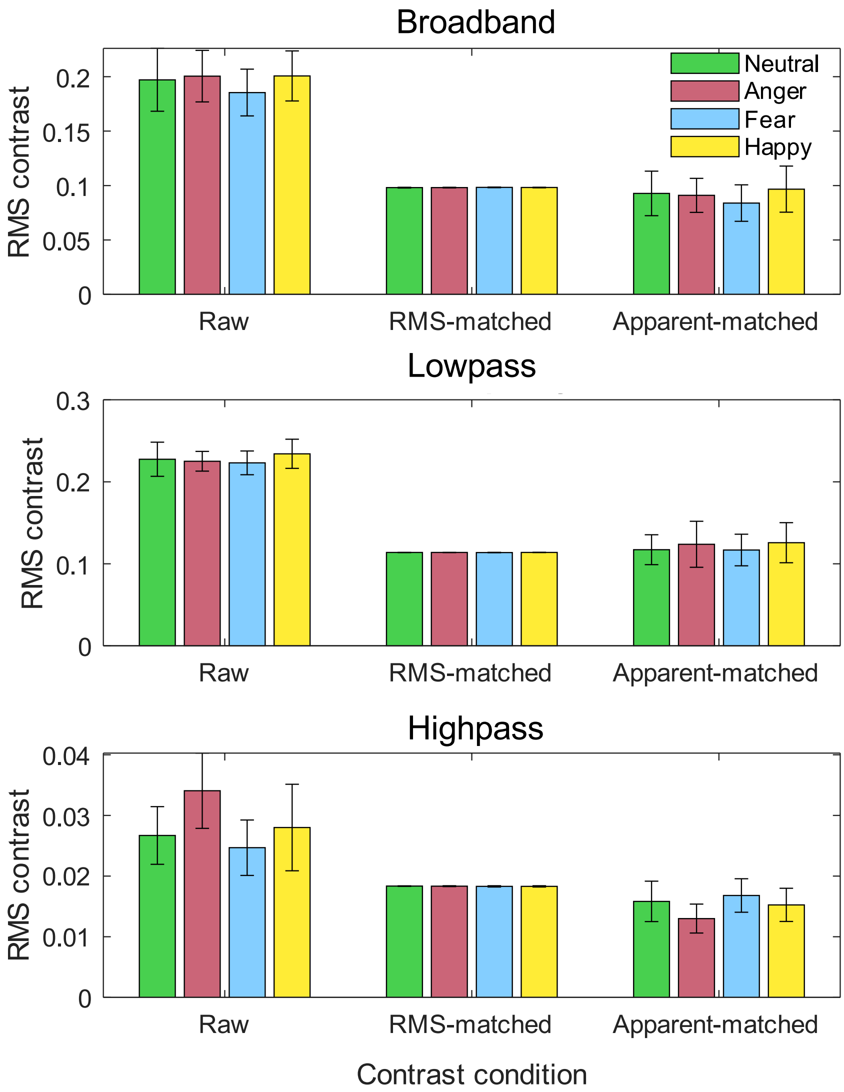

Figure 1: Expression-related differences in mean contrast as a function of spatial-frequency filtering and contrast-matching condition. Error bars represent ±1 standard deviation.

Faces were presented in one of two ways: in their natural, upright format, and in a manipulated format in which they were rotated 180° and subjected to luminance polarity reversal. This method for creating control faces significantly disrupts facial emotion recognition while preserving their low-level image properties including their spatial frequency amplitude spectrum and contrast [32,45]. It should be noted however that there are mixed findings regarding the effect of luminance polarity reversal on the salience of faces, where some evidence implies that the increase in darker local regions enhances stimulus visibility [45].

Procedure

All observers began the study with a verbal briefing and a 9-point calibration, according to the default EyeLink 1000 calibration program. No practice trials were provided. Participants were instructed to press the space-bar when ready to begin a new trial. Each trial commenced with a single fixation cross appearing at the centre of the screen for a pseudorandom time interval between 250-1000 ms. This fixation cross was immediately followed by a face target appearing to the left or right of centre, with equal numbers of trials on each side, which remained on the screen for 200 ms. The distance between the centre of each face and the centre of the screen was 7°. Observers were instructed simply to “look towards” the face image as soon as it appeared. Each trial was separated by a 200 ms gap, and before the onset of each trial, a default EyeLink 1000 drift correction, or re-calibration function, was used to ensure that each observer started each new trial from the same location, looking at the centre of the screen. There was a total of 720 trials (10 (actor) x 4 (expression) x 3 (frequency) x 3 (contrast) x 2 (format)). Trials were separated into 3 blocks according to spatial frequency (broadband, low-pass, and high-pass stimuli). Within these blocks, the order of presentation was randomised. Stimuli were separated by frequency due to the large difference in visibility associated with spatial frequency filtering. The order of blocks was randomised between participants. The trial sequence can be seen in Figure 2.

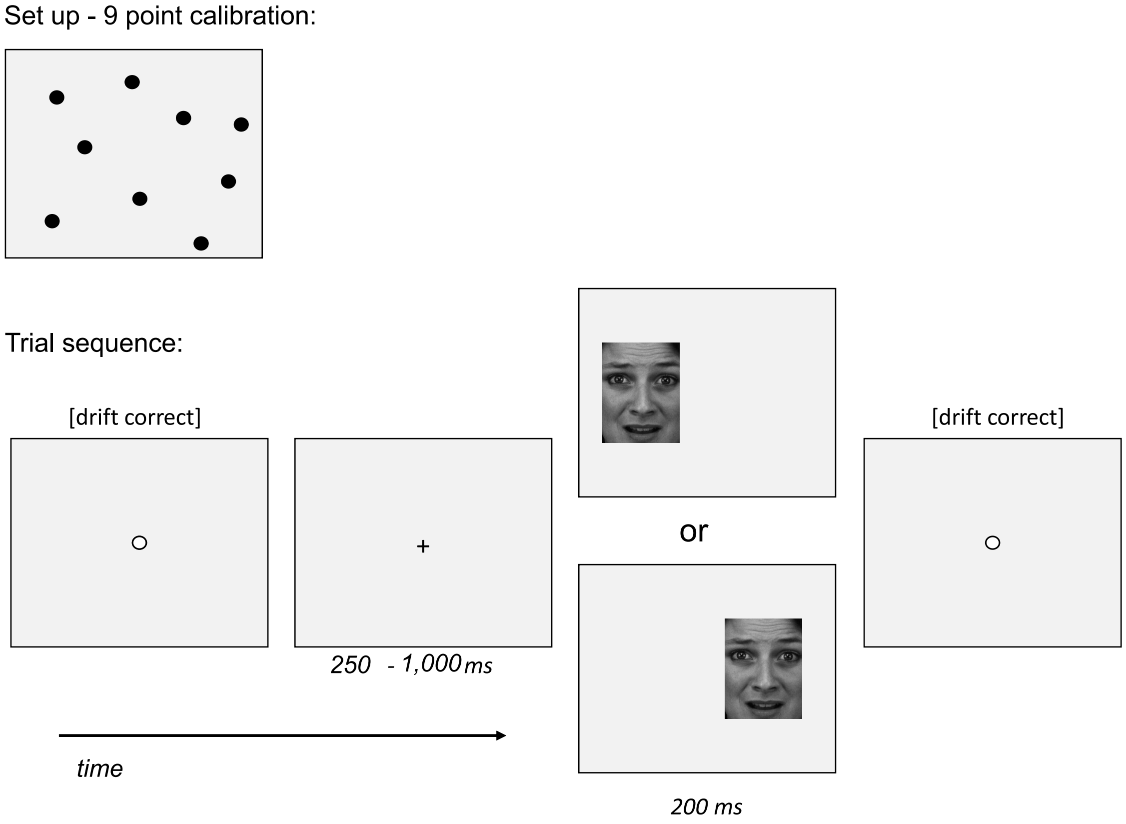

Figure 2 Schematic representation of the task: each trial began with a central fixation point whose function was also to drift correct (to ensure that observers were looking at the centre of the screen and to maintain calibration). A fixation cross appeared for a pseudorandom time interval, followed by a facial expression to the left or right of the screen, appearing for 200 ms. Participants were instructed to simply look towards the face as quickly and accurately as possible.

Results

Saccade responses were measured in milliseconds; shorter responses denote faster saccades towards faces. On trials where more than one saccade was made, only the first orienting saccade was extracted for data analysis. Data were analysed using a linear mixed effects model with the ‘fitlme’ function in MATLAB.

The primary objective of the current study was to determine whether the threat-bias was evident across different conditions of spatial frequency filtering (broadband, low-pass filtered and high-pass filtered) and contrast (raw original contrast, RMS matched and perceptually matched). For this reason, separate models were fit for each of these nine combinations of frequency filtering and contrast matching. According to the threat bias, we would predict shorter saccadic latencies for fearful faces in comparison with all other facial expressions, and neutral faces. Based on previous literature, we also predicted that the threat bias would not be present for high-pass filtered stimuli, as it has been argued to be driven by low spatial-frequency information [13, 18].

We predicted that saccadic latencies would be longer for lower contrast stimuli, and for those that have been high-pass filtered [30]. These stimuli had a lower RMS contrast due to the amplitude spectra of portrait photographs [42].

The manipulation of the orientation and polarity of the stimuli could have two possible, alternative effects. The first is that, by disrupting the recognition of the stimuli as faces, saccadic latencies might be increased, if faces were more salient than other stimuli. Alternatively, if latencies depend on low-level image properties, we would not expect latencies to be longer for the manipulated stimuli [32]. Indeed, it might even be expected that manipulated faces would be responded to more quickly, due to the effect of polarity reversal on the distribution of intensity levels [36,45].

The categorical fixed effects for each model were 'expression' and 'face format' (original versus rotated and polarity inverted stimuli), including the expression-by-format interaction, to measure the effects of face format manipulation on face detection between various emotions. The random effects were defined as intercepts over 'participant' and 'face image actor', due to possible variability related to individual differences, and the use of 10 actors selected from the KDEF database. This random effects structure was chosen based on a comparison of AIC values for alternative models fitted with a maximum likelihood procedure. Once the model was chosen, it was refit with a restricted maximum-likelihood procedure, and the fixed-effects denominator degrees of freedom were calculated using a Satterthwaite approximation [46]. This method has been shown to provide a more conservative test of significance [47]. Our conclusions were not affected by our choice of this approach.

We were also interested in the overall effect of non-emotional, low-level properties of the stimuli on saccadic latencies. An additional model was therefore fit to assess the effects of contrast, spatial frequency filtering and 'face-format' (whether or not it was rotated and polarity-inverted).

Broadband facial stimuli

Figure 3 shows saccadic responses for broadband facial expressions when they are (a) raw contrast, (b) matched for RMS contrast, and (c) matched for apparent contrast. The linear mixed effects models for these three conditions are tabulated in Appendix A.1. For raw contrast, broadband stimuli, saccadic responses for normally-presented (upright, retained luminance polarity) fearful faces did not differ compared to those for neutral, angry or happy faces. When the same faces were presented in manipulated format (inverted, reversed luminance polarity), saccadic response times were, overall, slower. In this condition, saccadic response times for fearful expressions were significantly slower for fearful compared to neutral faces.

For broadband faces matched for RMS contrast, saccadic responses for normally-presented fearful expressions did not differ compared to those for neutral, angry, or happy faces. When the same faces were presented in manipulated format (inverted, reversed luminance polarity), saccadic response times were faster overall. In this condition, saccadic responses for fearful expressions were significantly faster compared to manipulated neutral and angry faces.

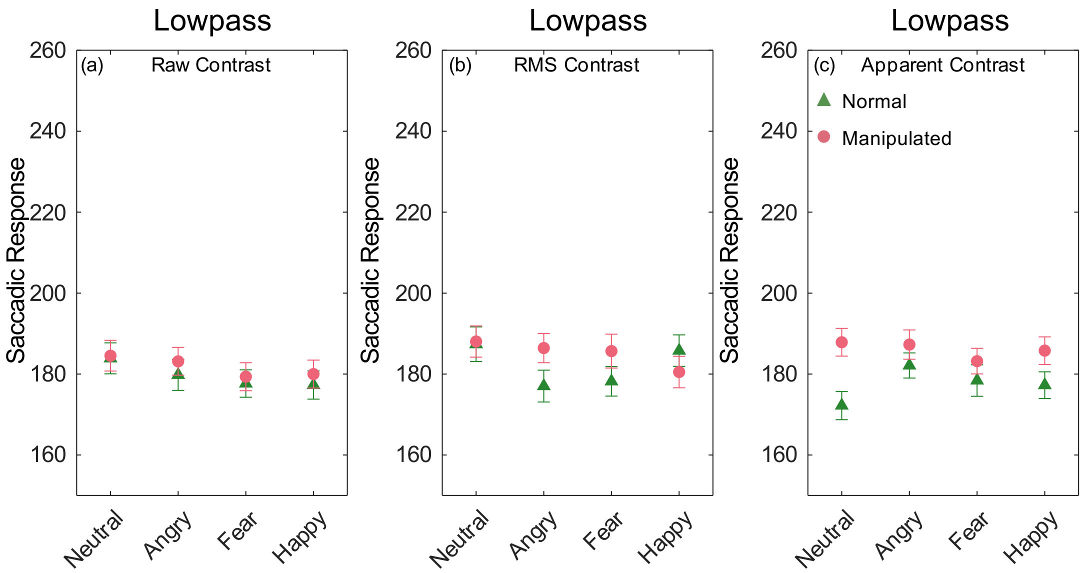

Figure 3 Mean saccadic responses (ms) for broadband-frequency facial stimuli in response to expressions: Neutral, Angry, Fear and Happy. Individual plots show responses to (a) raw contrast (b) normalised for RMS contrast and (c) normalised for apparent contrast stimuli. Green triangles show the data upright faces, and pink circles show the data for manipulated faces (face format). Green triangles show the data upright faces, and pink circles show the data for manipulated faces (face format). Error bars are ±1 SEM.

For broadband faces matched for apparent, perceived contrast, saccadic response times did not differ between expressions, regardless of the format in which they were presented. There was no overall significant effect of face format.

Low-pass facial stimuli

Figure 4 shows mean saccadic responses for low-pass facial expressions when they are (a) raw contrast (b) matched for RMS contrast, and (c) matched for apparent contrast. The linear mixed effects models for these three conditions are summarisesd in Appendix A.2. For low-pass filtered stimuli, there were no significant effects of facial expression, or image manipulation, in any of the contrast-matching conditions.

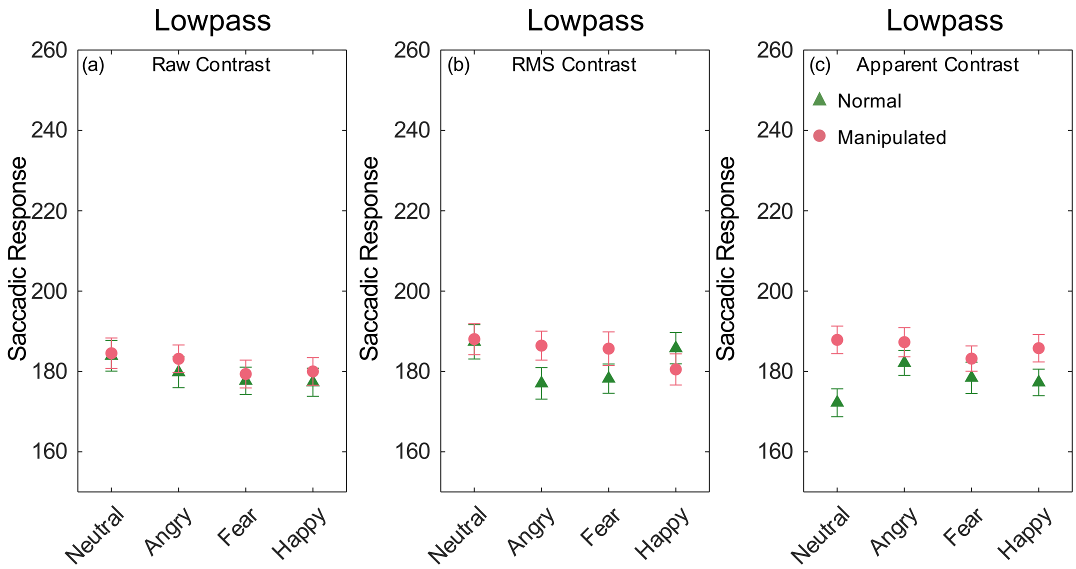

Figure 4 Mean saccadic responses (ms) for low-pass facial stimuli in response to expressions: Neutral, Angry, Fear and Happy. Individual plots show responses to (a) raw contrast (b) normalised for RMS contrast and (c) normalised for apparent contrast stimuli. Green triangles show the data upright faces, and pink circles show the data for manipulated faces (face format). Error bars are ±1 SEM.

High-pass facial stimuli

Figure 5 shows saccadic responses for high-pass facial expressions when they are (a) raw contrast (b) matched for RMS contrast and (c) matched for apparent, perceived contrast. The linear mixed effects models for these three conditions are summarised in Appendix A.3. For high-pass filtered stimuli, there were no significant effects of facial expression, or image manipulation, in any of the contrast-matching conditions.

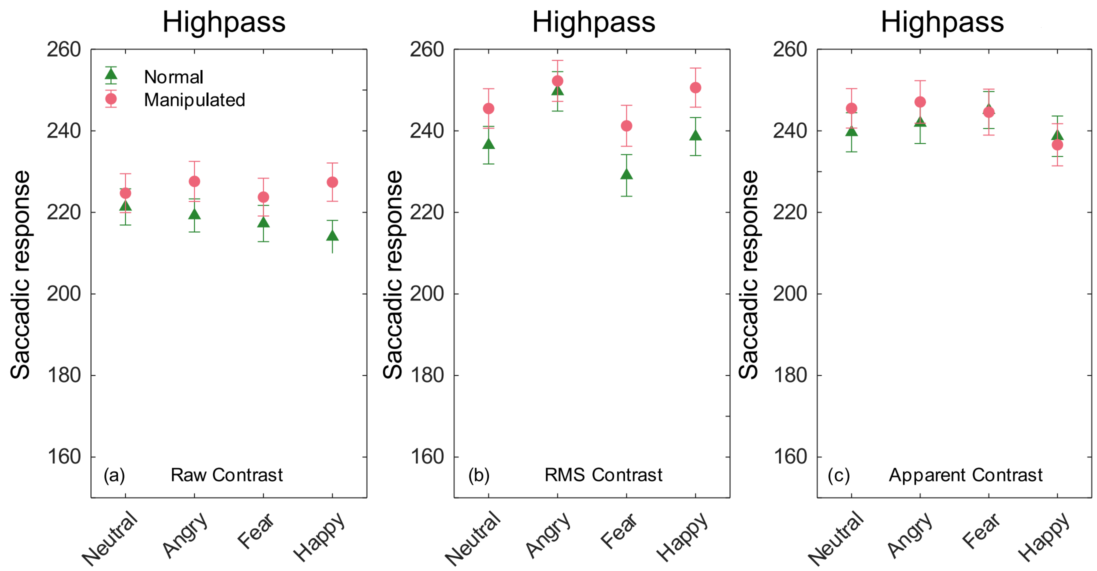

Figure 5 Mean saccadic responses (ms) for high-pass facial stimuli in response to expressions: Neutral, Angry, Fear and Happy. Individual plots show responses to (a) raw contrast (b) matched for RMS contrast and (c) normalised for apparent contrast stimuli. Green triangles show the data upright faces, and pink circles show the data for manipulated faces (face format). Green triangles show the data upright faces, and pink circles show the data for manipulated faces (face format). Error bars are ±1 SEM.

Saccadic amplitudes

The same models were also applied to assess the effects of the emotional content of stimuli on saccadic amplitudes. On average, saccades were close to the centre of the stimuli (at an eccentricity of 7˚), with a mean amplitude of 6.97˚. There were no significant effects of facial expression or face-format on saccadic amplitudes, for any of the combinations of frequency filtering and contrast matching.

Overall effects of low-level image properties

Figure 6 shows the effects of low-level image properties on saccadic reaction times. We fit a model to all the data with frequency filtering, contrast matching and image format as the three fixed-effect categorical predictors. Random intercepts across both participants and actors were again included in the model, and the fitting procedure was the same as for the models of expression and face-format. This model is summarised in Appendix A.4.

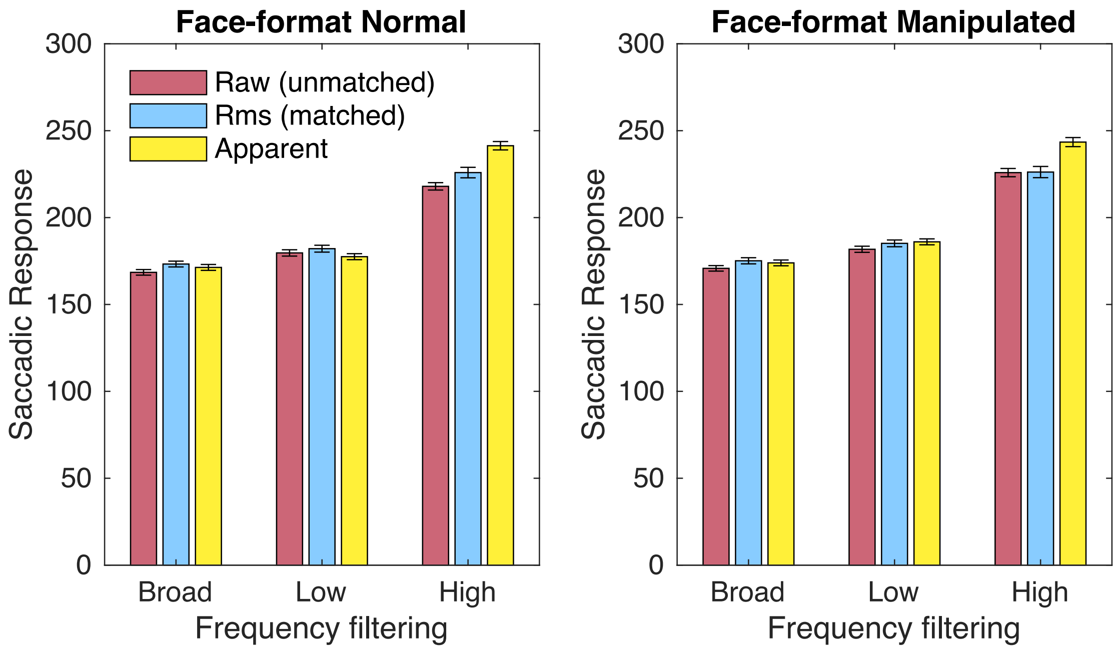

Figure 6 The effects of image manipulation, frequency filtering and contrast normalisation on mean saccadic responses (ms), combined across all facial expressions. Error bars are ±1 SEM.

Saccadic response times were slower for low-pass filtered stimuli than for broad-band stimuli, and slower still for high-pass filtered stimuli. Saccadic response times were also slower for RMS matched and perceptually-matched stimuli than for raw contrast stimuli. Finally, reaction times were marginally slower for manipulated stimuli.

The same model was also applied to assess the effects of low-level image properties on saccadic amplitudes. On average, saccades were close to the centre of the stimuli (at an eccentricity of 7°), with a mean amplitude of 6.97°. Saccadic amplitudes were smaller for the lower contrast RMS matched (β=-0.16(0.05), t=-3.24, p=0.001) and perceptually-matched (β=-0.12(0.05), t=-2.86, p=0.004) stimuli, and for low-pass (β=-0.15(0.04), t=-3.39, p=0.001) and high-pass filtered (β=- 0.63(0.05), t=-12.87, p < 0.001) stimuli.

Summary of findings

Saccadic responses are overall slower for high-pass stimuli, regardless of expression and contrast matching. In terms of biased saccadic responses for fearful facial expressions, no effects were observed for typical, upright stimuli, regardless of their spatial frequency content. In some instances, however, we observed mixed findings for fearful faces presented in manipulated format. For example, we observed a saccade bias for manipulated broadband fearful faces when matched for RMS contrast that becomes a disadvantage when not matched for contrast at all. Importantly, though we observed few differences in saccadic responses to fear compared to other faces, these differences almost completely vanished across all frequency conditions when expressions were normalised for their apparent contrast. Saccadic responses were however affected by low-level image properties, being slower when stimuli were lower in contrast, manipulated, low-pass filtered and, in particular, high-pass filtered. The implications of these findings for the threat bias literature, and for image standardisation procedures, are discussed in the following section.

Discussion

The present study was motivated by the threat bias literature, particularly that which proposes a unique bias for responding to, and processing, fearful facial stimuli. Findings thus far are relatively mixed, and are derived from a range of experimental paradigms [2,3,7,8,9,11,12,13,14,16,19,33]. From these findings, the role of spatial frequency, presentation duration, and response mode remain unclear. Saccadic latency is considered to be a favourable approach over manual response modes, because it indexes implicit and reflexive responses to stimuli as they become available in the visual field [6,30]. Despite this, the role of low-level image information on saccadic responses to facial emotional displays, including spatial frequency and contrast, remains relatively unexplored. To investigate this, we measured saccadic response times for neutral, angry, fearful and happy faces, when presented in broadband format, or when low-pass or high-pass filtered. To assess the role of contrast normalisation, faces were shown in their raw contrast format, or when matched for RMS contrast or apparent contrast. Findings from the present study can be separated into three main areas: (i) findings regarding the threat bias for spatially filtered fear expressions, (ii) the overall effect of contrast and spatial frequency filtering on saccadic responses, and (iii) detectability of upright faces versus those subjected to spatial inversion and luminance polarity reversal.

No saccadic latency biases for spatially-filtered fear expressions

For typical, broadband facial stimuli, saccadic response times did not differ for fearful facial displays compared to neutral, angry, or happy faces. Although this finding is at odds with studies showing faster detection and processing time associated with fearful faces [3,8,13,16,18,32], it contributes to, and is consistent with, a growing body of literature showing the absence of a threat bias for fearful facial displays [8,10,14,19,48,49]. We also did not find any evidence of detectability advantages for fearful expressions when low-pass or high-pass filtered.

There is some disagreement regarding the role of spatial frequency for rapid fear processing, where Bannerman et al. [13] show response biases for low-pass fearful faces, and Stein et al. [18] show biases only for high-pass stimuli. It is, however, necessary to note here that in a small number of cases, we observed both faster and slower saccadic response times for control fearful faces (e.g. when spatially inverted and subjected to reversed luminance polarity). The fact that these effects differed according to spatial frequency content and contrast condition suggests a role of low-level image information in determining these effects, as opposed to the face as a fearful expression. Together, findings from the present study provide no evidence that fearful expressions receive prioritised access to attentional resources, and instead show that saccadic initiation is influenced not by the emotional content of faces, or their expression-related low-level differences, but by overall salience of the face as an image.

Saccadic responses are influenced by image contrast

We assessed the degree to which saccadic responses were influenced by the overall physical composition of faces, independently of expression-related effects. We found that response times for detecting raw contrast stimuli, containing the highest average contrast, were faster than for faces with a lower contrast, suggesting that saccades are 'drawn to' physically salient facial images, regardless of their emotional relevance. This 'image effect' is further supported by the finding that saccadic response times were also slowest for high-pass filtered face images, which have a naturally lower contrast. Overall, these findings are consistent with known effects of contrast and spatial frequency on saccadic latencies [41].

Finally, previous literature regarding the extent to which low-frequency-dependent fear bias effects are accounted for by spatial frequency effects (greater contrast at spatial frequency ranges in line with 'low-pass' conditions), are also not supported here. This is because the present findings show that saccadic responses are overall faster for broadband versus low-pass facial stimuli.

It is difficult to directly compare the contrast-related effects found in the present study to those from similar experimental designs. Details regarding contrast differences between images, the extent to which they are matched, and using which contrast metrics, are not always consistently reported in the literature. However, the role of contrast alone cannot account for all findings. Bannerman et al. [13], or example, show clear saccadic biases for fearful faces that were not matched for contrast. Given this, we should have expected to observe the same effect in the present broadband condition, but we did not. Moreover, Khalid et al. [11] did match stimuli for contrast, and found no fear bias compared to neutral faces. Also, Webb and Hibbard [33] found that contrast normalisation of facial stimuli *facilitates* biases for detecting fear expressions. Notably, these examples come from studies using different experimental parameters, and it is likely that the role of image contrast differs relative to the task at hand. Recently, there has been an emerging view that contrast normalisation can inadvertently either boost [33,36] or impede [39] performance on facial emotion tasks, dependent on the details of the normalisation process and task used. While the present findings do not show a facilitatory effect of contrast normalisation on fear detection biases [19,33,36], they do suggest that improved performance for fearful faces *not* normalised for contrast [39] may be due to the fact that these faces, compared to those matched for physical or apparent contrast, are already advantaged by having a higher contrast.

Saccades do not always rely on holistic facial information

A final area of interest was the role of face format, or the use of control facial stimuli, on saccadic response times. The present study created control versions of facial stimuli using spatial inversion combined with luminance polarity reversal, a combined treatment known to significantly impede emotion recognition [32]. Recently, however, some evidence suggests that luminance polarity reversal may, in some cases, inadvertently increase the perceived salience of a control face [45]. Saccadic latency is therefore an ideal candidate for exploring these effects, particularly because findings regarding the effects of holistic information in upright versus inverted faces for saccadic responses are fairly mixed. Khalid et al. [11], for example, found that performance was better for inverted over upright facial stimuli, while Bannerman et al. [12] showed the opposite effect. In the present study, saccadic response times did not differ according to the format of broadband facial stimuli. This result suggests that saccadic latency is indifferent to the holistic information present in upright faces, and depends primarily on low-level visual features. This is an unexpected outcome given the known face inversion effect that is consistently observed for regular, unfiltered faces [45,50]. Unmanipulated faces did, however, receive faster saccadic response times when faces were low-pass and high-pass filtered. This was influenced by the use of contrast matching. Detectability advantages for upright low-pass faces relied on their apparent contrast, while detectability advances for high-pass faces relied on naturally-occurring contrast differences between expressions. These findings are consistent with previous literature, in that they demonstrate a complex interaction between contrast, luminance, and orientation for facial emotion processing [33,36].

Future replication

A replication of the present study might investigate in more detail the role of image presentation duration, particularly because the degree to which threat biases occur in response to transient versus consciously-evaluated faces remains unclear. Bannerman and colleagues [12,13] suggest that for longer face durations (500 ms and above), manual rather than saccadic responses are the preferred response mode, and that saccadic responses are more appropriately explored using very short stimulus presentations, below 200 ms. Despite this, Seitz and colleagues [31], for example, showed that the eyes of fearful faces were located faster compared to happy faces when available for 150 ms, but not compared to neutral or angry faces, showing that biases for detecting threat-relevant information in fear expressions is possible in a simple localisation task, even at 150 ms durations. Similarly, fearful face precues shown for both 100 and 500 ms have also been shown to have no effect on search efficiency, [48], while other instances evidence improved search efficiency following exposure to fearful faces for 500 as opposed to 100 ms [49]. Moreover, regardless of the stimulus duration length, it is generally accepted that longer durations (500 and 5000 ms) are capable of eliciting overall faster saccadic responses for stimuli (regardless of expression) compared to manual ones [12, 31], suggesting that this mode of response can generally sample, and respond to, visual information at a faster rate than is possible using manual responses.

It might also be important to understand the generalisability of the results across different populations. For example, in common with other studies [12,13,18] the majority (65%) of our participants were female. A small but consistent difference in sensitivity to facial emotion recognition has been found, such that women tend to be more sensitive than men [51]. It would be interesting therefore to assess this directly therefore in the context of saccadic response times.

Conclusion

Our findings show that saccadic eye movements are largely indifferent to the emotional content of facial stimuli, and that factors including image contrast and spatial frequency are more likely to influence the speed with which saccades are deployed. These findings contribute to a growing body of literature demonstrating an absence of threat bias effects for fearful faces, and further demonstrate that the simple image properties of facial stimuli, and the degree to which they are adjusted during image standardisation, can have significant effects on behavioural performance on facial emotion tasks.

Appendix A. Tables

Table A.1: **Linear mixed effects models (3) summarising saccadic responses for broad-band facial stimuli, at each contrast condition.**

	β	SE	tStat	df	p	CI (95%)
(a) Saccadic responses to raw contrast (unmatched), broadband faces						
Intercept (Fear)	165.39	5.25	31.48	40.71	< .001	154.78, 176
Fear-Neutral	+5.82	4.09	1.42	1810	0.15	-2.20, 13.85
Fear-Anger	+3.84	4.09	0.94	1810	0.35	-4.19, 11.86
Fear-Happy	+2.7	4.09	0.66	1810	0.51	-5.32, 10.73
Manipulation	+9.94	4.09	2.43	1810	0.015*	1.91, 17.96
Fear-Neutral*manipulation	-13.83	5.79	-2.39	1810	0.017*	-25.18, -2.48
Fear-Anger*manipulation	-9.72	5.79	-1.68	1810	0.093	-21.07, 1.60
Fear-Happy*manipulation	-6.98	5.78	-1.21	1810	0.23	-18.31, 4.37
(b) Saccadic responses to RMS-matched, broadband faces						
Intercept (Fear)	175.24	5.52	31.79	43.17	< .001	164.11, 185.38
Fear-Neutral	-0.57	4.44	-0.13	1801	0.90	-9.27, 8.12
Fear-Anger	-1.69	4.44	-0.38	1801	0.70	-10.39, 7.00
Fear-Happy	-5.64	4.44	-1.27	1801	0.20	-14.34, 3.06
Manipulation	-8.03	4.44	-1.81	1801	0.07	-16.73, 0.67
Fear-Neutral*manipulation	+15.40	6.27	2.46	1801	0.014*	3.10, 27.71
Fear-Anger*manipulation	+13.28	6.27	2.12	1801	0.034*	0.98, 25.58
Fear-Happy*manipulation	+10.90	6.27	1.74	1801	0.08	-1.40, 23.20
(c) Saccadic responses to apparent-matched, broadband faces						
Intercept (Fear)	172.22	5.22	33.01	49.17	< .001	161.74, 182.71
Fear-Neutral	-0.52	4.41	-0.12	1801	0.91	-9.16, 8.12

Fear-Anger	-2.52	4.41	-0.57	1801	0.57	-11.16, 6.12
Fear-Happy	-0.59	4.41	-0.13	1801	0.89	-9.23, 8.05
Manipulation	2.72	4.41	0.62	1801	0.54	-5.90, 11.36
Fear-Neutral*manipulation	-0.57	6.22	-0.09	1801	0.93	-12.79, 11.66
Fear-Anger*manipulation	3.80	6.23	0.61	1801	0.54	-8.42, 16.02
Fear-Happy*manipulation	-3.68	6.23	-0.59	1801	0.56	-15.90, 8.54

Table notes : * indicates significant p-value. Sub-tables are for (a) raw contrast , not-normalised, RMS-normalised and (c) psychophysically normalised for apparent, perceived contrast. For each sub-table Fear is the intercept, and reports the estimated response time in milliseconds (ms) for the normal face condition. The *face-format effect* reflects the change in slope for the manipulated face, with fear as the reference and the estimated response time in (ms).

Table A.2: **Linear mixed effects models (3) summarising saccadic responses for low-pass facial stimuli, for each contrast condition.**

	β	**SE**	**tStat**	**df**	***p***	**CI (95%)**
(a) Saccadic responses to raw contrast (unmatched), low-pass faces						
Intercept (Fear)	177.66	6.06	29.30	41.22	< .001	165.41,189.90
Fear-Neutral	6.23	4.57	1.37	1801	0.17	-2.72,15.19
Fear-Anger	2.14	4.57	0.47	1801	0.64	-6.81,11.09
Fear-Happy	-0.36	4.57	-0.08	1801	0.94	-9.31,8.59
Manipulation	1.70	4.57	0.37	1801	0.71	-7.25,10.66
Fear-Neutral*manipulation	-1.07	6.45	-0.17	1801	0.87	-13.73,11.60
Fear-Anger*manipulation	1.64	6.45	0.25	1801	0.88	-11.67,13.66
Fear-Happy*manipulation	1.00	6.44	0.15	1801	0.88	-11.68,13.66
(b) Saccadic responses to RMS-matched, low-pass faces						
Intercept (Fear)	178.20	6.06	29.41	50.00	< .001	166.02,190.37
Fear-Neutral	9.18	5.13	1.79	1801	0.07	-0.86,19.24
Fear-Anger	-1.16	5.13	-0.23	1801	0.82	-11.21,8.89
Fear-Happy	7.50	5.13	1.46	1801	0.15	-2.58,17.52
Manipulation	7.47	5.13	1.46	1801	0.15	-2.58,17.52
Fear-Neutral*manipulation	-6.81	7.25	-0.94	1801	0.35	-21.03,7.41

Fear-Anger*manipulation	1.92	7.25	0.27	1801	0.79	-12.30,16.14
Fear-Happy*manipulation	-12.76	7.25	-1.76	1801	0.08	-26.98, 1.46
(c) Saccadic responses to apparent-matched, low-pass faces						
Intercept (Fear)	178.41	5.55	32.12	43.03	< .001	167.21, 189.61
Fear-Neutral	-6.19	4.43	-1.40	1801	0.16	-14.87,2.49
Fear-Anger	3.71	4.43	0.84	1801	0.40	-4.97,12.39
Fear-Happy	-1.15	4.43	-0.26	1801	0.80	-9.83,7.53
Manipulation	4.79	4.43	1.08	1801	0.28	-3.88,13.47
Fear-Neutral*manipulation	10.85	6.26	1.73	1801	0.08	-1.42,23.13
Fear-Anger*manipulation	0.38	6.26	0.06	1801	0.95	-11.90,12.65
Fear-Happy*manipulation	3.73	6.26	0.60	1801	0.55	-8.54,16.00

Table notes : For each sub-table Fear is the intercept (β), and reports the response time in milliseconds (ms). * indicates significant p-value. Sub-tables are (a) raw contrast, not-normalised, (b) RMS-normalised, (c) psychophysically normalised for apparent, perceived contrast.

Table A.3: **Linear mixed effects models (3) summarising saccadic responses for high-pass facial stimuli, at each contrast condition.**

	β	**SE**	**tStat**	**df**	***p***	**CI (95%)**
(a) Saccadic responses to raw contrast (unmatched), high-pass faces						
Intercept (Fear)	217.27	6.49	33.50	58.97	< .001	204.30, 230.25
Fear-Neutral	4.07	6.02	0.68	1801	0.50	-7.73,15.88
Fear-Anger	1.99	6.02	0.33	1801	0.74	-9.82,13.79
Fear-Happy	-3.28	6.02	-0.54	1801	0.59	-15.08,8.53
Manipulation	6.47	6.02	1.08	1801	0.28	-5.33,18.28
Fear-Neutral*manipulation	-3.11	8.51	-0.37	1801	0.72	-19.80,13.59
Fear-Anger*manipulation	1.87	8.51	0.22	1801	0.83	-14.83,18.56
Fear-Happy*manipulation	6.95	8.51	0.82	1801	0.41	-9.75,23.64
(b) Saccadic responses to RMS-matched, high-pass faces						
Intercept (Fear)	229.83	10.62	21.64	42.89	< .001	208.41,251.25
Fear-Neutral	-4.63	7.74	-0.60	1523	0.55	-19.82,10.55
Fear-Anger	-1.09	7.68	-0.14	1522	0.89	-16.15,13.97
Fear-Happy	-13.31	7.81	-1.70	1522	0.09	-28.632.00
Manipulation	-9.23	7.70	-1.20	1523	0.23	-24.33,5.88

Fear-Neutral*manipulation	6.80	10.92	0.62	1523	0.53	-14.63,28.22
Fear-Anger*manipulation	14.46	10.99	1.32	1523	0.19	-7.09,36.01
Fear-Happy*manipulation	16.56	10.99	1.51	1522	0.13	-5.00,38.13
(**c) Saccadic responses to apparent-matched, high-pass faces**						
Intercept (Fear)	245.10	6.8	35.93	74.44	< .001	231.51,258.69
Fear-Neutral	-5.45	6.82	-0.80	1801	0.42	-18.83,7.92
Fear-Anger	-3.16	6.82	-0.46	1801	0.64	-16.54,10.22
Fear-Happy	-6.42	6.82	-0.94	1801	0.35	-19.80,6.95
Manipulation	-0.52	6.82	-0.08	1801	0.94	-13.90,12.85
Fear-Neutral*manipulation	6.38	9.64	0.66	1801	0.51	-12.53,25.30
Fear-Anger*manipulation	5.67	9.64	0.59	1801	0.56	-13.25,24.585
Fear-Happy*manipulation	-1.57	9.64	-0.16	1801	0.87	-20.49,17.34

Table notes : Broadband, raw contrast, unmanipulated stimuli are the intercept (β), response times are in milliseconds (ms). * indicates significant p-value.

Table A.4: **Linear mixed effects models summarising the effects of contrast matching, manipulation and spatial frequency filtering on saccadic responses.**

	β	**SE**	**tStat**	**df**	***p***	**CI (95%)**
Intercept	160.94	5.02	32.085	52.35	< .001	150.87, 171.01
RMS	6.68	1.28	5.22	15796	< .001 *	4.17 , 9.19
Apparent	8.17	1.10	7.44	16218	< .001 *	6.02,10.34
Manipulation	3.44	0.90	3.81	16218	< .001	1.68 , 5.22
Low-pass	9.89	1.10	9.00	16218	< .001 *	7.73 , 12.04
High-pass	60.78	1.28	47.49	15796	< .001 *	58.27 , 63.28

Table notes : The broadband, raw contrast, unmanipulated version of the face is the intercept, and response times are in milliseconds (ms). * indicates significant p-value. Sub-tables are saccadic responses to normal faces at each frequency condition.

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