The effects of spatial frequency on the decoding of emotional facial expressions

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Abstract

The accurate identification of emotion is critical to effectively navigating our social lives. However, it is not clear how distinct types of visual information afford the accurate perception of others' emotion states. Here, we sought to examine the influence of different spatial frequency visual information on emotion categorization, and whether distinctive emotional dimensions (valence and arousal) are differentially influenced by specific spatial frequency content. Across one pilot and two experiments ($N = 603$), we tested whether emotional facial expressions that vary in valence, arousal, and functional significance differ in accuracy of categorization as a function of low, intact, and high spatial frequency band information. Overall, we found a general decrease in the breadth of emotional expressions for filtered images but did not see a decrease in accuracy of categorization for the positive emotion, joy. Together, these results suggest that spatial frequency information influences perception of emotional expressions that differ in valence and arousal.

Keywords: emotion, face perception, spatial frequency filtering

The effects of spatial frequency on the decoding of emotional facial expressions

In many commonplace circumstances, as in poor lighting conditions at night, or a drizzly afternoon—people are forced to make judgments about what and whom we see on the basis of sub-optimal visual input. Yet even when viewing times are extremely short, these decisions are remarkably accurate and extend to the traits and concepts associated with a face (e.g., Todorov et al., 2009; Verosky et al., 2018). This ability—the rapid and accurate perception of faces—underscores the richness of facial information. Facial expressions are powerful signals about the states of others and can inform adaptive behavior for the individual (Parkinson, 2005). Extensive research has examined the ways that emotional displays are perceived (e.g., dimensional vs. discrete; Ekman, 1992; Russell, 1980), but open questions remain about the mechanisms that support the perception of facial expressions, and which signals—coarse visual information or fine-grained details—guide discrimination between similar emotion states. Here, we investigate the role of spatial frequency information in facial expressions of emotions that vary in their functional significance (i.e., emotions that tend to evoke approach or avoid tendencies; Fontaine, 2007; Harmon-Jones, 2019), valence, and arousal.

Facial Expressions of Emotion

Emotion expression and perception are critical to survival. Expressing emotions allows us to regulate how much sensory information to intake (Susskind et al., 2008), and perceiving emotional expressions are vital to effective social cognition (see Adolphs, 2003). Facial expressions of emotions offer a real-time peek into the inner worlds of the individuals with whom we interact. Indeed, research on basic emotions suggests that facial expressions are not only important to successful communication (Blair, 2003; Haxby et al., 2002), but in some

instances transcend cultural and phylogenetic boundaries (Darwin, 1872; Ekman, 1992; Ekman, 1993; but see Barrett, 2011; Chen & Jack, 2017; Russell, 1994)¹.

These expressions are rich forms of nonverbal communication that have been well explored within the literature. For example, empirical evidence suggests that facial expressions of emotion quickly recruit neural circuitry dedicated to the processing of faces (or other expertly tuned categories like birds) and salient stimuli (Gauthier et al., 2000; Tanaka & Curran, 2001). What's more, emotional, compared to neutral, facial expressions elicit more activity in face-selective regions (e.g., fusiform face area) in the brain (see Tsao & Livingston, 2008; Weiner & Grill-Spector, 2013 for review) and in the amygdala (Morris et al., 1998; Vuilleumier et al., 2004; Diano et al., 2017), which is a structure modulated by emotional value and novelty (among other things; Anderson & Phelps, 2001; Bzdok et al., 2013; Schwartz et al., 2003). Further, facial expressions of emotion dominate perceptual experience when pitted against one another in binocular rivalry (Alpers & Gerdes, 2007; Pasley et al., 2004), can be perceived unconsciously (Dimberg et al., 2000), and capture attention (Sawada & Sato, 2015; Vuilleumier & Schwartz, 2001) when compared to neutral faces or objects. Altogether, both neural and behavioral evidence points to the importance of emotional expressions in human social cognition.

One critical function of facial expressions is that they afford communicating and transferring information between a sender and receiver about oneself and the environment (see Jack & Schyns, 2015). The distance between a sender and receiver also affects what information is extracted from emotional expressions, and it is critically tied to the functional significance of specific emotions: Previous research suggests that happy and surprise facial expressions are most

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¹ There is, of course, a longstanding debate about the generalizability of “basic emotions”. While acknowledging this debate, we focus instead on the conceptual and functional information available within commonly labeled facial expressions.

accurately recognized at further distances than emotions whose proximal utility is higher—like sadness or fear (Du & Martinez, 2011; Smith & Schyns, 2009). Unlike communicating joy which tends to lead to global processing (see Clore & Huntsinger, 2007) and may signal affiliative intentions (e.g., Knutson, 1996), the communication of fear often entails quick examination of the nearby surroundings for threats. While the perception of emotional expressions recruits specific neural architecture, are visually prioritized, and are sensitive to the informational value communicated between sender and receiver, the present research examines what features of available visual information adequately communicate specific emotion content to receivers.

Spatial Frequencies and Face Perception

Face processing, like other forms of visual processing, relies on both coarse visual information (e.g., roughly defined, low-level cues like the location of arrangement of face parts and general outline of the face) and finely grained details (e.g., eye-size, lip-curl, etc.). These different streams of information are conveyed by dissociable bands of spatial frequency information. Specifically, low spatial frequency bands convey coarse-grained (i.e., blurry without details) visual information (Goffaux et al., 2003; Goffaux & Roisson, 2006; Sergent, 1986; but see Cheung et al., 2008) that can be seen from further distances. In contrast, high spatial frequency bands provide finely detailed visual information (e.g., Goffaux et al., 2005) that require closer proximity. Critically, the coarse visual information available in low spatial frequency bands is also the earliest information available during the visual cascade—coarse information is processed very quickly, followed by the processing of the finer-grained details available in high spatial frequency bands (Bullier 2001; Bar, 2007; Chen et al., 2018; Goffaux et al., 2011). Research using electroencephalogram methods suggests that while high-spatial-frequency-biased stimuli induced only weak face-selective activity at 75 ms of exposure, low-

spatial-frequency-biased stimuli elicit strong activity at that exposure time (Goffaux et al., 2011). Moreover, research examining rapid saccadic choice suggests that low spatial frequency information (compared to high spatial frequencies) initiates the perception of faces (Guyader et al., 2017). Taken together, these findings suggest that low spatial frequency information may play a pivotal role in accurate perception of faces.

Consistent with this notion, the literature also points to an important role for low spatial frequency bands and the identification of particular emotional expressions. For example, much of this work has focused on the identification of fearful faces because it is adaptive to accurately, and quickly, identify signals of threat (e.g., Ohman & Mineka, 2001; Vlamings et al., 2009; Vuilleumier et al., 2003; Winston et al., 2003). Expressions of fear presented with only low spatial frequency information available increase amygdala activation at early stages of face processing (Alorda et al., 2007; Vuilleumier et al., 2003; Mermillod et al., 2009), and they increase event-related peak amplitudes associated with face processing compared to neutral face expressions (Vlamings et al., 2009). That is, low spatial frequency information may also scaffold the perception of facial expressions of emotions.

However, low spatial frequency information is not always sufficient for the decoding of important facial expression signals. For example, when comparing happy and sad facial expressions, research has found that low-pass filtered faces facilitated the identification of happy expressions, but that high spatial frequency filtered faces facilitated the identification of sad expressions (Kumar & Srinivasan, 2011). Here, there is a dissociable influence of the spatial frequency information available, and the ability to recognize a specific facial expression. Further, research comparing accuracy of children versus adults' emotion identification found that while the discrimination of angry compared to happy faces in low spatial frequencies resulted in

increased error rates, performance was unimpaired when faces were presented in high spatial frequencies independent of participant age (Deruelle & Fagot, 2005). Interestingly, the categorization of targets as male or female was unimpeded when spatial frequency information was manipulated, suggesting that spatial frequency filtering had a unique effect on the identification of emotional expressions (versus identity; Deruelle & Fagot, 2005). These findings point to important roles for both low and high spatial frequency bands in the processing of different facial expressions of emotion.

Despite the large literature on the perception of faces and facial expressions, major questions remain about the unique role different spatial frequency information play in the perception of facial expressions of emotion. As the literature currently stands, it is difficult to disentangle whether the mixed results on perceptual differences in facial emotion perception are driven by differences in the functional role of a given emotion (e.g., smiles are easily recognizable regions of a face; Calvo & Nummenmaa, 2008), specific to the function of that emotion, or features of the emotions—like the perceived arousal, valence, or motivational direction conveyed by the emotional targets (e.g., Park et al., 2016; see also Lundqvist et al., 2014). Previous work on what visual information is communicating these critical behaviors has largely focused on one of these dimensions (e.g., valence; Alorda et al., 2007), but here, we aim to further the understanding of how spatial frequency content influences the processing of specific emotional expressions that vary along arousal, valence affective dimensions, and that differ in their functional utility. To our knowledge, there have been no systematic comparisons between accuracy of emotion identification for emotions that vary in valence, arousal, and their function (e.g., fear and disgust are both negative and typically arousing, but disgust motivates

reduction in information acquisition while fear promotes and increase in information acquisition; Susskind et al., 2008) across spatial frequency bands.

Overview

The present experiments investigated how disrupting the processing of facial expressions by manipulating spatial frequency content affects the accuracy of emotion expression categorization and emotional intensity. We examine whether emotional valence, arousal intensity, or functional significance of an emotion best characterize the critical signal in the accurate identification of emotion. Other research has used a similar approach—treating facial expressions as a decoding problem for the social mind (Smith et al., 2005; Schyns et al., 2009). When considering what emotional signal best characterizes the discriminability of a particular emotion from another, valence and arousal are often investigated (e.g., Russell, 2003). However, some research suggests that valence and arousal signals emanating from the face are not sufficient to distinguish amongst the content of various emotions (Aviezer et al., 2012; Fontaine et al., 2007; Carver & Harmon-Jones, 2009), and signals present in some expressions tend to be initially confused (Jack et al., 2014). As such, we sought to compare the accuracy of identification of emotions that vary along the dimensions of valence (negative vs. positive), arousal (high arousal vs. low arousal), and their functional significance. We used spatial frequency filtering to modulate the visual processing of stimuli to better understand what information conveys the critical signal to communicate the selected emotions.

This aim was tested across one pilot experiment and two experiments, using ratings of emotion negativity, arousal, and the target emotion categorization as the primary dependent variables. For experiments 1 and 2, we preregistered and investigated competing predictions: On the one hand, we might expect that emotional expressions presented in low spatial frequency

(low-pass filtered), which disrupts processing local information that can be emotion-diagnostic (e.g., eyes; Vaidya et al., 2014), will be the most difficult to accurately identify and discriminate amongst. In this case, we predict that emotion categorization will be most accurate for non-filtered images (i.e., intact spatial frequency images or ISF), followed by high spatial frequency (HSF), and then low spatial frequency (LSF) images. On the other hand, we might expect that biasing an image to quickly engage the amygdala (Bar et al., 2006; Vuilleumier et al., 2003) would lead to enhanced accuracy for emotion categorization. In this case, we predict that participants' ratings for LSF images will be similar to those of non-filtered image but enhanced compared to HSF images.

We also examine how spatial frequency manipulations affects perceptions of arousal intensity and emotional valence. For each of these judgments, we test the same competing hypotheses noted above with one exception: we predicted that approach-oriented compared to withdrawal-oriented emotions would be perceived as most arousing and emotionally intense (in their respective valence directions). That is, unlike fear, anger and joy are approach-oriented emotions where direct eye gaze is consistent with the emotional category (see Adams & Kleck, 2003), which suggests that the visual cues to those emotions will not be ambiguous. We predicted that this consistency would lead to enhanced perceptions of the arousal and valence dimensions because the signal from the disrupted faces contains less conflicting visual information (i.e., there is less ambiguous information to decode). Thus, perception of those emotions was predicted to be enhanced relative to the other emotions, regardless of spatial frequency filtering.

In the pilot experiment, we set out to compare emotions that differed in each of the dimensions of interest: valence, arousal, and functional significance. As such, we compared fear,

joy, surprise and anger in an exploratory manner to test whether there are differences in accuracy of categorization and ratings for the different spatial frequency bands. Experiments 1 and 2 build off of the pilot and focus on what specific features of emotions are conveyed by different spatial frequency content. Experiment 1 investigates differences in ratings and categorization for emotions matched on (negative) valence but differing in arousal and functional significance (fear, anger, and disgust). Experiment 2 investigates differences in ratings and categorization for emotions matched on (high) arousal but differing in valence and functional significance (fear, joy, and surprise). Both Experiment 1 and 2 were preregistered prior to data collection on the Open Science Framework (<https://osf.io/vz2k8/>). Materials, analysis code, and stimuli from all experiments (including the pilot) are available on the project's OSF page.

Pilot

Design

The pilot experiment was a 3 (spatial frequency: LSF, HSF, ISF) $\times$ 4 (emotion: fear, joy, surprise, anger) fully within-subjects design, counterbalanced across participants so that all participants saw each identity displaying each emotion in only one spatial frequency category. There were three target dependent variables: emotion valence (i.e., how positive/negative), arousal (i.e., how arousing), and emotion expression category judgment.

Participants

We recruited a sample of 55 participants using the subject pool at a public, urban university in the United States for course credit (24 males, 29 females, 2 did not report, $M_{age} = 22.58$, $SD_{age} = 4.28$; 45.28% Asian, 3.77% Black, 16.98% Latino/a, 28.3% White, 5.66% Other). Given that this was a pilot, we recruited participants until the end of the semester without a specific target sample in mind.

Materials

Stimuli

Stimuli for this experiment were 30 unique identities (15 male and 15 female White individuals) taken from the Warsaw Set of Emotional Facial Expression Pictures (Olszanowski et al., 2015). Selected faces were subjected to high-pass (HSF; faces without low spatial frequencies), intact-pass (ISF; i.e., unfiltered faces), or low-pass filtering (LSF; faces without high spatial frequencies), using the ImageJ software package (Schneider et al., 2012). Each image was first converted to grayscale and then batch filtered using the FFT bandpass filter tool. The generation of LSF images matched that of previous research such that structures between 60 and 999 pixels were retained and autoscaling was allowed (values approximate Schyns & Oliva, 1999). The same process was used to generate the HSF versions of images, retaining structures between 5 and 25 pixels, again allowing for autoscaling (see Figure 1). This yielded a total of 120 stimuli per counterbalanced block (360 stimuli in total).

Figure 1. Example of a single identity intact in grayscale (ISF), with low frequencies removed (HSF), and with high frequencies removed (LSF).

Emotion ratings

We included two items to assess the valence and arousal of the emotional facial expressions. For arousal, we used a 9-point Likert scale that ranged from 1 = *not at all*, 5 =

somewhat, and 9 = *extremely* aroused. For valence, we used a zero-centered Likert scale ranging from $-4 = \text{very negative}$, $0 = \text{neutral}$, to $+4 = \text{very positive}$.

Emotion categorization

The primary dependent variable was the accuracy of emotion category identification. Participants had unlimited time to select which of four categories (fear, anger, joy, surprise) best describes the facial expression they viewed.

Procedure

Consenting participants first saw a facial expression from a single identity (presented in random order) presented on screen for the duration it took for participants to make their ratings. Participants rated the image on arousal, negativity, and then made a categorization judgment, with these ratings being made in a random order. The trials progressed after participants finished their ratings and pressed the ‘next’ key. Participants completed a total of 120 trials presented in random order, and then completed demographic questions and were debriefed. Counterbalancing was set such that participants saw each identity in only one of the three spatial frequency conditions, though saw each face displaying each of the four emotions (i.e., rated each target face four times). Thus, targets appearing in LSF in one counterbalanced block would appear in HSF in another, and ISF in yet another. This way we are able to isolate the effect of spatial frequency filtering on emotion displays per target without additional noise introduced by crossing individual targets across multiple repeated measures.

Results

Analyses were conducted using R statistical analysis software (R Core Team, 2019), using mixed effects models that specify random intercepts for participants and stimuli using the ‘lme4’ package (Bates et al, 2015) and the ‘lmerTest’ package (Kuznetsova et al., 2017) to

compute model p -values using Satterthwaite's approximation. We investigated each dependent variable (arousal, valence, and accuracy) separately. We test pairwise differences between marginal means with linear models using the 'emmeans' package (Lenth, 2020). For the pilot study, analyses focus on differences between HSF and LSF content on perception of emotional expressions to target how the two different spatial frequency bands affect decoding of emotional facial expressions. We report results from each contrast analyses (including the ISF control) in the Supplementary Materials.

For emotion identification, we computed d' (sensitivity) for use in a signal detection analysis². Because we had four distinct emotion categories, we computed d' for each emotion separately by computing the average number of hits and false alarms for each, then subtracting the rate of false alarms from the rate of hits (these indices were computed using the 'psycho' package in the R programming language; Makowski, 2018). Once d' was computed for all emotions in isolation, these values were combined into a single data frame, and then were entered into a repeated-measures ANOVA that tested for effects of spatial frequency filtering, emotion category, and their interaction.

Arousal

We regressed arousal ratings onto spatial frequency category, emotion, and their interaction term and then conducted an ANOVA on this model. We found a main effect of spatial frequency, $F(2, 348.19) = 13.37, p < .001, \eta_p^2 = .07$, and a main effect of emotion category, $F(3, 348.18) = 179.65, p < .001, \eta_p^2 = .61$. These main effects were qualified by a significant interaction, $F(6, 348.19) = 2.13, p = .049, \eta_p^2 = .04$. Contrasts suggested that perception of arousal was lower for angry and fearful faces when presented with LSFs intact

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² We also calculated β (bias) scores. Those results are reported in the supplemental materials.

compared to HSFs ($\text{HSF}_{\text{angry}}: p < .001$, 95% CI_b [.23, .76]; $\text{HSF}_{\text{fear}}: p = .01$, 95% CI_b [.08, .69]), but no differences between LSF and HSF emerged for joyous and surprised faces ($p = .97$; $p = .79$, respectively).

Valence

We again found a significant main effect of spatial frequency, $F(2, 347.24) = 6.16$, $p = .002$, $\eta_p^2 = .03$, and a significant main effect of emotion category, $F(3, 347.22) = 1544.83$, $p < .001$, $\eta_p^2 = .93$. These effects were qualified by a significant interaction, $F(6, 347.23) = 2.27$, $p = .04$, $\eta_p^2 = .04$. Contrasts suggested that while valence perception of fearful and surprised targets were not significantly different across all three spatial frequency bands ($p = .14$, $p = .07$, respectively), angry targets in LSF (vs. HSF) were perceived as less negative ($p = .04$, 95% CI_b [−.55, −.008]). Joyous targets presented in LSF were not significantly different than those presented in HSF ($p = .45$).

Emotion Detection

Sensitivity

There was a main effects for spatial frequency, $F(2, 572) = 16.91$, $p < .001$, $\eta_p^2 = .06$, such that d' for HSF targets was higher compared to LSF targets ($p < .001$, 95% CI_b [.13, .33]). There was also a main effect for emotion category, $F(3, 572) = 554.74$, $p < .001$, $\eta_p^2 = .74$, on sensitivity scores such that angry and joyous targets were highest in sensitivity compared to fearful and surprise (see Table 1). However, the interaction term was not significant, $F(6, 572) = .63$, $p = .71$, $\eta_p^2 < .001$ (see Figure 2).

Table 1.

Emotion Type	<i>b</i>	<i>SE</i>	<i>t</i>	<i>d</i>	95% <i>CI</i>
<i>Anger</i>					
Fear	1.39***	0.05	27.13	1.13	[1.26, 1.52]
Joyous	−.34***	0.05	−6.73	−.28	[−.48, −.21]

Surprise	1.61***	0.05	22.70	.95	[1.03, 1.29]
<u>Joyous</u>					
Fear	-1.73***	0.05	-33.86	-1.42	[-1.86, -1.60]
Surprise	1.51	0.05	29.43	1.23	[1.37, 1.64]
<u>Fear</u>					
Surprise	-.23***	0.05	-4.43	-.19	[-.36, -.09]

Note: * $p < .05$, ** $p < .01$, *** $p < .001$.

Figure 2. Mean sensitivity (d') scores for each emotion, based on spatial frequency filtering. Error bars represent 95% CIs.

Discussion

The pilot experiment suggested that spatial frequency filtering impacts the perception of valence and arousal in varying ways. Perception of arousal appears to be dampened when HSFs

are removed for targets displaying negative emotions, independent of the functional significance of those emotions. For valence, LSFs blunted perceptions of emotional valence (relative to HSFs and ISFs), leading perceivers to view such targets as closer to neutral. That is, the disruption of featural processing may decrease the breadth of emotional expressions being perceived—across both valence and arousal.

Broadly, participants accurately identified emotions displayed in HSF bands, but were less accurate identifying emotions displayed in LSF bands. Further, sensitivity analyses suggested that anger and joyous expressions were similarly accurately detected, but differentiating between fearful and surprised targets, regardless of spatial frequency content, was challenging. This suggests that highly arousing approach-signaling emotion expressions may have a perceptual advantage compared to avoidance-signaling emotion expressions, regardless of their spatial frequency content. However, these results suggest differences in the perception of facial expressions of emotion for valence and arousal without clear patterns. We did, however, find that emotions which tend to be processed more globally (e.g., Clore & Huntsinger, 2007) and successfully communicated at farther distances saw a slight advantage in identification relative to the other emotions examined. Thus, we designed Experiments 1 and 2 to better understand which facets of emotional expressions are influenced by spatial frequency filtering matching on one dimension to better control the comparisons among discrete emotion expressions.

Experiment 1

In Experiment 1, we isolated three negatively valenced emotions (fear, anger, and disgust) to explore the effects of spatial frequency filtering on emotion identification when arousal varies between these functionally difference emotions. Here, we predicted that, following

data from the pilot experiment, disrupting bottom-up facial processing should decrease accuracy when facial expressions signal similar content. Emotion identification sensitivity was predicted to be lowest for LSF targets than for either HSF or ISF targets. As noted earlier, we also set out to test competing hypotheses: emotions presented in low spatial frequency (low-pass filtered) will be the most difficult to accurately identify because of low-level disruptions to face processing or they will be enhanced due to biasing faces toward low-spatial frequency which quickly engage the amygdala. Given that ISF images contain both HSF and LSF information, we examined whether HSF or LSF images were more similar in patterns to perceptions of ISF face images. If HSF or LSF content closely mirrors perceptions of ISF content, then this would be good evidence that the isolated frequency content is crucial to that aspect of emotional expression identification. Lastly, we also predicted that, because of the threatening approach-orientation of anger, angry targets would be rated as the most emotionally negative (vs. fearful and disgusted targets) in the ISF and HSF conditions.

Methods

Design

Experiment 1 used a 3 (spatial frequency: LSF, HSF, ISF) by 3 (emotion: fear, disgust, anger) fully within-subjects design, again counterbalanced across participants so that participants saw each target display all three emotions in only one spatial frequency band. The target dependent variables mirrored that of the pilot³.

Participants

We recruited a sample of 206 participants using the subject pool at an urban, public university in the United States (58 males, 110 females, 38 did not report, $M_{age} = 21.15$, $SD_{age} =$

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³ We also asked participants to rate how confident they were in their emotion categorization. Those results are reported in the supplementary materials.

5.04; 34.46% Asian, 7.28% Black, 17.48% Latino/a, 0.48% Native American, 17.96% White, 22.33% Other). An *a priori* power analyses using PANGEA (Westfall, 2015) indicated that data from 150 participants would yield 80.8% power to detect a minimum effect of $d = .20^4$. The power analysis was conducted specifying the most stringent contrasts, those being the average of two conditions contrasted against one condition in both the spatial frequency and emotion factors (i.e., a -1, -1, 2 contrast for both factors) for all linear mixed effects models.

Materials

Stimuli. The stimulus filtering method matched that of the pilot experiment. We used the same faces for the fear and anger emotion, and selected faces from the same dataset for the disgust faces (Warsaw Set of Emotional Facial Expression Pictures; Olszanowski et al., 2015). Across the three counterbalance blocks, this yielded a total of 90 stimuli (270 images across the entire set of blocks).

Emotion ratings. The emotion ratings mirrored the pilot, but each were rated on a scale ranging from 1 to 7. The arousal ratings were measured from 1 = *extremely low arousal* to 7 = *extremely high arousal*. The valence ratings were measured from 1 = *not at all* to 7 = *extremely negative*.

Emotion categorization. The emotion categorization measure was the same as in the pilot.

Procedure

The procedure matched that of the pilot experiment with two exceptions. First, faces were displayed for only 1000ms before disappearing (see also Tracy et al., under review). Second,

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⁴ We also conducted a second power analysis for ANOVAs, which indicated that 150 participants would yield 82.7% power to detect a minimum effect of $d = .22$

participants also rated their confidence in the accuracy of their categorization judgment (reported in the Supplementary Materials).

Results

For the analyses of arousal and valence we entered participants' scores into a linear mixed effects model that regressed each dependent variable on the three-level spatial frequency factor, the three-level emotion category factor, and their interaction term, computing an ANOVA on this model to determine significant differences. Degrees of freedom were obtained using Satterthwaite's approximation. This model also included random intercepts for participants and stimuli.

Arousal

Our analyses of participants' ratings of emotional arousal yielded a significant main effect of spatial frequency, $F(2, 16254) = 142.57, p < .001, \eta_p^2 = .02$, a main effect of emotion category, $F(2, 16252) = 75.53, p < .001, \eta_p^2 = .01$, and significant spatial frequency $\times$ emotion category interaction, $F(4, 16252) = 3.03, p = .02, \eta_p^2 = .001$ (see Figure 3). Consistent with our preregistration, we conducted pairwise comparisons using contrast analyses for arousal ratings for each emotion prior to exploring the interaction effect. Contrary to our preregistered hypothesis, participants rated anger as lower in arousal than disgust, $b = -.22, SE = .03, t(16252) = -7.47, p < .001, d = -.06, 95\% CI_b [-.29, -.15]$. Similarly, angry targets were perceived as less aroused than fearful targets, $b = -.36, SE = .03, t(16252) = -12.19, p < .001, d = -.10, 95\% CI_b [-.43, -.29]$, as were disgusted targets, $b = -.14, SE = .03, t(16250) = -4.70, p < .001, d = -.04, 95\% CI_b [-.21, -.07]$.

We next decomposed the interaction by exploring the effect of spatial frequency at each individual emotion.

Figure 3. Mean arousal ratings for each emotion at each spatial frequency band in Experiment 1. Error bars represent 95% CIs.

For angry targets, we found a significant effect of spatial frequency filtering, $F(2, 5273.9) = 54.72, p < .001, \eta_p^2 = .02$. No significant differences emerged between ISF and HSF targets for arousal, $p = .69$, 95% CI_b [- .16, .08]. However, participants rated targets as lower in arousal for LSF compared to both ISF ($b = .43, SE = .05, t(5273) = 8.63, p < .001, d = .12$, 95% CI_b [.32, .55]) and HSF ($b = .47, SE = .05, t(5274) = 9.44, p < .001, d = .13$, 95% CI_b [.36, .59]) targets.

For fearful targets, we again found a significant effect of spatial frequency, $F(2, 5282.7) = 30.71, p < .001, \eta_p^2 = .01$. Arousal ratings did not differ between ISF and HSF targets, $p = .19$, 95% CI_b [- .03, .21], but were lower for LSF targets relative to ISF ($b = .38, SE = .05, t(5282) = 7.49, p < .001, d = .10$, 95% CI_b [.26, .50]) and HSF ($b = .29, SE = .05, t(5283) = 5.76, p < .001, d = .08$, 95% CI_b [.17, .41]) targets.

The same patterns emerged for disgusted targets, $F(2, 5263.2) = 70.53, p < .001, \eta_p^2 = .03$. Arousal ratings were the same for ISF and HSF targets, $p = .83$, 95% $CI_b [-.15, .09]$. Arousal was significantly lower LSF targets compared to ISF ($b = .49, SE = .05, t(5264) = 9.97, p < .001, d = .14$, 95% $CI_b [.38, .61]$) and HSF ($b = .52, SE = .05, t(5264) = 10.58, p < .001, d = .15$, 95% $CI_b [.41, .64]$) targets.

We conducted additional simple effects tests, comparing the arousal ratings of each emotion at each level of spatial frequency. These analyses can be found in the Supplementary Material. In general, these analyses support the argument that not all emotions are equally affected by spatial frequency filtering, and instead renders the perception of arousal to be closer for some emotions though not for others.

Valence

The model of participants' negativity ratings revealed a main effect of spatial frequency, $F(2, 16255) = 164.03, p < .001, \eta_p^2 = .02$, and a main effect of emotion category, $F(2, 16254) = 144.58, p < .001, \eta_p^2 = .02$, which were qualified by a significant two-way interaction, $F(2, 16254) = 12.96, p < .001, \eta_p^2 = .003$ (see Figure 4). As with arousal ratings, we conducted pairwise comparisons for negativity ratings across the three emotion categories. Contrary to our hypothesis, we found that angry targets were rated as less negative than disgusted targets, $b = -.09, SE = .03, t(16254) = -2.67, p = .02, d = -.02$, 95% $CI_b [-.16, -.01]$, but more negative than fearful targets, $b = .42, SE = .03, t(16254) = 13.21, p < .001, d = .10$, 95% $CI_b [.35, .50]$. Disgusted targets were also rated as more negative than fearful targets, $b = .51, SE = .03, t(16253) = 15.87, p < .001, d = .12$, 95% $CI_b [.43, .58]$. We next decomposed the interaction.

Figure 4. Mean negativity ratings for each emotion at each spatial frequency band in Experiment 1. Error bars represent 95% CIs.

For angry targets, there were no differences in negativity between ISF and HSF targets, $p = .65$, 95% $CI_b [- .18, .08]$. However, negativity was significantly lower for LSF compared to ISF ($b = .62$, $SE = .06$, $t(5274) = 11.23$, $p < .001$, $d = .15$, 95% $CI_b [.49, .75]$) and HSF ($b = .67$, $SE = .06$, $t(5275) = 12.10$, $p < .001$, $d = .17$, 95% $CI_b [.54, .79]$) targets.

For fearful targets, the effect of spatial frequency was again significant, $F(2, 5283.2) = 12.32$, $p < .001$, $\eta_p^2 = .005$. The patterns from contrast analyses followed anger. There were no differences in negativity ratings between ISF and HSF targets, $p = .81$, 95% $CI_b [- .16, .09]$. But, again, negativity was lower for LSF compared to ISF ($b = .21$, $SE = .05$, $t(5282) = 3.95$, $p < .001$, $d = .05$, 95% $CI_b [.08, .33]$) and HSF ($b = .24$, $SE = .05$, $t(5284) = 4.58$, $p < .001$, $d = .06$, 95% $CI_b [.12, .36]$) targets.

We found another significant effect of spatial frequency for disgusted targets, $F(2, 5262.5) = 101.7, p < .001, \eta_p^2 = .04$. No differences emerged in negativity between ISF and HSF targets, $b = -.03, SE = .05, t(5262) = -.61, p = .82, d = -.008, 95\% CI_b [-.15, .09]$. ISF targets were rated as more negative than LSF targets, $b = .62, SE = .05, t(5263) = 12.02, p < .001, d = .17, 95\% CI_b [.50, .74]$, while HSF targets were more negative than LSF targets, $b = .65, SE = .05, t(5263) = 12.66, p < .001, d = .17, 95\% CI_b [.53, .78]$.

As with the arousal ratings, we conducted alternative simple effects tests to decompose the significant interaction. These can be found in the Supplementary Materials section. We again find support for the claim that spatial frequency filtering does not produce unilateral effect on all emotions, but instead more sharply blunts some emotions but not others.

Emotion Categorization

We computed the same signal detection indices used in the pilot experiment, calculating participants' sensitivity (d') separately for each emotion. We then entered these into repeated-measures ANOVAs with degrees of freedom computed via Satterthwaite's approximation. We also calculated bias (β) scores, and we report those in the supplemental material.

Sensitivity

Our initial model found a significant main effect of spatial frequency, $F(2, 1532.9) = 331.05, p < .001, \eta_p^2 = .30$, as well as a significant main effect of emotion category, $F(2, 1529.7) = 104.97, p < .001, \eta_p^2 = .12$. These main effects were qualified by a significant interaction between spatial frequency and emotion category, $F(4, 1529.7) = 13.55, p < .001, \eta_p^2 = .03$ (see Figure 6). We conducted simple effects tests for the effect of spatial frequency for each emotion (see the Supplementary Material for emotion-specific analyses at each spatial frequency band).

Figure 6. Mean sensitivity (d') scores for each emotion at each level of spatial frequency in Experiment 1. Error bars represent 95% CIs.

For angry targets, the effect of spatial frequency was significant, $F(2, 375.14) = 134.02, p < .001, \eta_p^2 = .42$. Contrast analyses revealed that sensitivity was higher for ISF than for HSF targets, $b = .20, SE = .06, t(375) = 3.34, p = .003, d = .17, 95\% CI_b [.06, .33]$, as well as LSF targets, $b = .91, SE = .06, t(375) = 15.54, p < .001, d = .80, 95\% CI_b [.77, 1.05]$. Moreover, sensitivity was also higher for HSF targets than for LSF targets, $b = .71, SE = .06, t(375) = 12.23, p < .001, d = .63, 95\% CI_b [.58, .85]$.

The effect of spatial frequency was significant for fearful targets, $F(2, 376.46) = 42.68, p < .001, \eta_p^2 = .18$. Contrasts found that participants were no differences in sensitivity to ISF and HSF targets, $p = .62, 95\% CI_b [-.08, .19]$. Participants were less sensitive to LSF targets than ISF

($b = .48$, $SE = .06$, $t(376) = 8.42$, $p < .001$, $d = .43$, 95% CI_b [.34, .61]) and HSF ($b = .42$, $SE = .06$, $t(377) = 7.50$, $p < .001$, $d = .41$, 95% CI_b [.29, .56]) targets.

For disgusted targets, there was a significant effect of spatial frequency, $F(2, 381.01) = 162.16$, $p < .001$, $\eta_p^2 = .46$. Participants' sensitivity scores did not differ between ISF and HSF targets, $p = .25$, 95% CI_b [−.05, .24]. Again, sensitivity scores were lower for LSF than ISF ($b = .98$, $SE = .06$, $t(381) = 16.31$, $p < .001$, $d = .84$, 95% CI_b [.84, 1.12]) and HSF ($b = .88$, $SE = .06$, $t(381) = 14.76$, $p < .001$, $d = .76$, 95% CI_b [.74, 1.03]) targets.

Discussion

We found mixed support for our hypotheses. Removing HSF information decreased perceptions of both arousal and negativity. Arousal judgments were the lowest for LSF targets, regardless of emotion, while HSF and ISF stimuli evinced no differences. Similarly, negativity judgments were lowest for LSF targets, despite the fact that the emotions displayed by targets in Experiment 1 were all negatively valenced. Further, participants' emotion detection accuracy (as measured by d') was lowest for target faces presented in LSF but was similar across both HSF and ISF trials. Taken together, results from Experiment 1 suggest that not only do LSFs impair the discrimination of different emotion displays, but also blunt the perceptions of a target's level of arousal and the overall negativity of that emotional display.

Interestingly, participants' sensitivity to fearful faces in the LSF trials were higher than their sensitivities to angry or disgusted faces, supporting the argument that LSFs are critical for identifying fear displays that signal potentially threatening situations. This is consistent with past evidence that LSF information is especially critical for quick identification of fearful expressions (e.g., Winston et al., 2003). Moreover, these results are also consistent with previous research that suggests task demands related to the number of emotions to choose between also influence

patterns of identification (Smith & Merlusca, 2014). Unlike the pilot experiment which did not subset emotional expressions based on their valence, when we changed the context of expressions in Experiment 1, we saw a shift in the patterns of results (Aviezer et al., 2008). In Experiment 2, we further explore how isolated visual information influences categorization and judgments of emotion displays by matching facial expressions on arousal.

Experiment 2

Experiment 2 investigated how the identification of highly arousing emotion states is influenced by spatial frequency manipulations. Here again, we predicted that images with only LSF content available would have the lowest ratings of arousal, valence, and have the lowest accuracy for emotion categorization. We also examined whether LSF or HSF images would be more similar in pattern to perceptions of ISF content.

Additionally, following the pattern of results from the pilot experiment, we also predicted that fear and surprise would not evidence any differences, but that ISF and HSF facial expressions would be rated higher in positivity than fear. Lastly, we predicted that joy (an approach-orientation emotion) would be rated as the most emotionally positive and highest in arousal compared to fearful and surprise facial expressions.

Methods

Design

The design of Experiment 2 matched that of the pilot and Experiment 1, using a 3 (spatial frequency) $\times$ 3 (emotion category) fully within-subjects design, but with one critical change: rather than being matched on emotional valence, we matched the emotions on arousal. The three emotions included were fear, joy, and surprise.

Participants

We again recruited a sample of 342 participants using the same subject pool as the pilot and Experiment 1 (115 males, 120 females, 107 did not report, $M_{age} = 27.34$, $SD_{age} = 10.81$; 15.20% Asian, 7.89% Black, 11.11% Latino/a, 1.17% Native American, 29.82% White, 34.80% Other). We conducted an *a priori* power analysis using PANGAEA (Westfall, 2015) that suggested that 150 participants were sufficient to detect an effect of $d = .22$.

Materials

Stimuli

The selected faces were from the same Warsaw Set of Emotional Facial Expression Pictures database (Olszanowski et al., 2015). This time the face targets selected displayed expressions of fear, joy, and surprise.

Emotion ratings

The emotions were rated using the same measures as Experiment 1.

Emotion categorization

The primary dependent variable was the accuracy of emotion category identification. Participants had unlimited time to select which of three categories (fear, anger, or disgust) best describes the facial expression they viewed.

Procedure

The procedure was identical to Experiment 1.

Results

Our analysis plan mirrored that of Experiment 1. We conducted ANOVAs on linear mixed models testing participants' ratings of each target's perceived emotional arousal and valence, along with their overall confidence in their judgments (reported in Supplementary Materials). Signal detection analyses of sensitivity (d') matched Experiment 1.

Arousal

We found a main effect of spatial frequency, $F(2, 25378) = 62.30, p < .001, \eta_p^2 = .005$ and emotion category, $F(2, 25378) = 187.99, p < .001, \eta_p^2 = .01$ on arousal ratings. However, the spatial frequency by emotion category interaction was not significant, $F(4, 25377) = .91, p = .46, \eta_p^2 = .0001$ (see Figure 7)⁵.

We again conducted contrast analyses using linear models to determine significant differences between factor levels. For the spatial frequency effect, we found no significant differences between ISF and HSF targets on arousal, $p = .26$, 95% CI_b $[-.02, .10]$. Arousal ratings were lower for LSF compared to ISF ($b = -.27, SE = .03, t(25377) = -10.36, p < .001, d = -.07$, 95% CI_b $[-.21, -.34]$) and HSF ($b = -.23, SE = .03, t(25379) = -8.78, p < .001, d = -.06$, 95% CI_b $[-.17, -.29]$) targets.

Emotion category contrasts suggested that participants rated fearful targets as being less aroused than joyous targets, $b = -.40, SE = .03, t(25378) = -15.18, p < .001, d = -.10$, 95% CI_b $[-.46, -.34]$, but more aroused than surprised targets, $b = .08, SE = .03, t(25379) = 2.88, p = .01, d = .02$, 95% CI_b $[-.01, .14]$. Joyous targets were also rated as more aroused than surprised targets, $b = .48, SE = .03, t(25378) = 18.03, p < .001, d = .11$, 95% CI_b $[-.41, .54]$.

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⁵ Despite the lack of conventional significance, we also conducted simple effects test on each emotion at each level of spatial frequency (as done in Experiment 1). These analyses can be found in the Supplementary Materials.

Figure 7. Mean arousal ratings for each emotion at each spatial frequency band in Experiment 2. Error bars represent 95% CIs.

Valence

For negativity ratings, we again found a significant main effect of spatial frequency, $F(2, 25380) = 11.73, p < .001, \eta_p^2 = .001$, and emotion category, $F(2, 25381) = 3280.63, p < .001, \eta_p^2 = .21$. These effects were qualified by a significant spatial frequency by emotion category interaction, $F(4, 25380) = 12.44, p < .001, \eta_p^2 = .002$ (see Figure 8). As with Experiment 1, we conducted pairwise comparisons on negativity ratings for each emotion to stay consistent with our preregistered hypothesis. Confirming our predictions, these analyses showed that fear was rated as more negative than joy, $b = 2.24, SE = .03, t(25381) = 80.15, p < .001, d = .50, 95\% CI_b [2.18, 2.31]$, and more negative than surprise, $b = .84, SE = .03, t(25381) = 29.87, p < .001, d =$

.19, 95% CI_b [.77, .90]. Joy was rated as less negative than surprise, $b = -1.40$, $SE = .03$, $t(25380) = -50.16$, $p < .001$, $d = -.31$, 95% CI_b [-1.47, -1.34].

Figure 8. Mean negativity ratings for each emotion at each spatial frequency band in Experiment 2. Error bars represent 95% CIs.

We next conducted simple main effects tests on the effect of spatial frequency for each individual emotion (see the Supplementary Materials for alternative emotion-specific analyses). For fearful targets, the effect of spatial frequency was significant, $F(2, 8255.5) = 17.77$, $p < .001$, $\eta_p^2 = .004$. Participants rated ISF faces as marginally less negative than HSF targets, $b = -.10$, $SE = .05$, $t(8256) = -2.07$, $p = .10$, $d = -.02$, 95% CI_b [-.21, .13]. Participants also rated LSF targets as significantly less negative than ISF ($b = -.18$, $SE = -.05$, $t(8256) = -3.81$, $p < .001$, $d = -.04$, 95% CI_b [-.07, -.29]) and HSF ($b = -.27$, $SE = -.05$, $t(8255) = -5.88$, $p < .001$, $d = -.06$, 95% CI_b [-.16, -.38]) targets.

For joyous targets, we again found a significant effect of spatial frequency, $F(2, 8247.2) = 23.37, p < .001, \eta_p^2 = .006$. Participants rated ISF targets as less negative than HSF targets, $b = -.17, SE = .04, t(8247) = -4.55, p < .001, d = -.05, 95\% CI_b [-.26, -.08]$, and LSF targets, $b = -.25, SE = .04, t(8248) = -6.70, p < .001, d = -.07, 95\% CI_b [-.33, -.16]$. Participants rated HSF targets as only marginally less negative than LSF targets, $b = -.08, SE = .04, t(8247) = -2.14, p = .08, d = -.02, 95\% CI_b [-.17, .007]$.

Lastly, we found a significant effect of spatial frequency on surprised targets, $F(2, 8201) = 8.31, p < .001, \eta_p^2 = .002$. Participants rated ISF targets as less negative than both HSF targets, $b = -.14, SE = .04, t(8201) = -3.12, p = .005, d = -.03, 95\% CI_b [-.24, -.03]$, and LSF targets, $b = -.17, SE = .04, t(8200) = -3.83, p < .001, d = -.04, 95\% CI_b [-.27, -.07]$. There were no significant differences between HSF and LSF targets, $p = .75, 95\% CI_b [-.14, .07]$.

Emotion Categorization

Similar to our approach for Experiment 1, we computed signal detection metrics of sensitivity (d') to analyze participants' emotion identification accuracy. Bias (β) is reported in the supplementary materials.

Sensitivity

Our analysis of participants' d' values yielded a main effect of spatial frequency, $F(2, 2566.8) = 88.69, p < .001, \eta_p^2 = .06$, and emotion category, $F(2, 2562.4) = 1462.35, p < .001, \eta_p^2 = .53$. The spatial frequency by emotion category interaction was not significant, $F(4, 2562.4) = .69, p = .60, \eta_p^2 = .001$ (see Figure 10)⁶.

For the effect of spatial frequency, participants' sensitivity scores were higher for ISF than for HSF ($b = .09, SE = .03, t(2566) = 3.57, p = .001, d = .07, 95\% CI_b [.03, .15]$) or LSF (b

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⁶ As with our arousal DV, we conducted the same simple effects test on differences for each emotion at each level of spatial frequency. These are also included in the Supplementary Materials.

$= .33$, $SE = .03$, $t(2566) = 12.90$, $p < .001$, $d = .25$, 95% CI_b [.27, .40]) targets. Sensitivity was also higher for HSF compared to LSF targets, $b = .24$, $SE = .03$, $t(2569) = 9.33$, $p < .001$, $d = .18$, 95% CI_b [.18, .30]. For the main effect of emotion category, participants' sensitivity scores were lower for fearful targets than for joyous targets, $b = -1.17$, $SE = .03$, $t(2562) = -45.24$, $p < .001$, $d = -.89$, 95% CI_b [-1.23, -1.11]. In contrast, sensitivity scores were higher for fearful than for surprised targets, $b = .08$, $SE = .03$, $t(2562) = 3.04$, $p = .007$, $d = .06$, 95% CI_b [.02, .14], and were higher for joyous targets than for surprised targets, $b = 1.25$, $SE = .03$, $t(2562) = 48.28$, $p < .001$, $d = .95$, 95% CI_b [1.19, 1.31].

Figure 10. Mean sensitivity (d') scores for each emotion at each level of spatial frequency in Experiment 2. Error bars represent 95% CIs.

Discussion

We again found that LSFs reduced perceptions of emotional arousal. However, critically, for negativity ratings, face targets displaying joy were rated as *more* negative (i.e., less positive) on LSF trials than on either HSF or ISF targets, which is consistent with previous research (Neta & Whalen, 2010). This suggests that when only LSF information is available for, the identification of negativity is impaired. When visual input was degraded (leaving LSF or HSF information) perceivers rated targets as closer to a prescribed neutral midpoint across the emotional spectrum. For emotion identification, participants were most accurate identifying the joyous targets, but were less able to differentiate between fearful and surprised targets. Contrary to Experiment 1, sensitivity to fearful targets saw no perceptual advantage—sensitivity was highest for detection of joyous targets. Given that research suggests that positive emotions are typically categorized faster (Kiritani & Endo, 1995; Leppänen & Hietanen, 2004) and more accurately (Du & Martinez, 2011), this pattern may reflect the ease of identifying a smile (Calvo et al., 2014). However, unlike previous research (Du & Martinez, 2011) we did not find that surprise was consistently accurately identified. Instead, we found that when the comparison emotions are similarly high in arousal to surprise, differentiating it from fear (and not joy) was diminished. This may stem from differences in the information available to discern between emotions. That is, previous research suggests that happy or joyous expressions are categorized using signal from both the mouth and the eyes, but surprise requires signal primarily from just the mouth and fear primarily from just the eyes (Schyns et al., 2009). When task demands required differentiating between only high arousal emotions and with only one (vs. two for joy) key sources of information to differentiate, we found that errors emerged when identifying surprise and fear. Moreover, regardless of the emotion being displayed, sensitivity was reduced during LSF trials relative to the accuracy observed during ISF and HSF trials, again suggesting

that blurring the featural boundaries in a target face dramatically reduces a perceiver's ability to identify the emotional content of that individual's face.

General Discussion

Across one pilot experiment and two preregistered experiments, the identification of facial emotion expressions was impaired when these emotions were presented with only LSFs available versus when they were presented with either HSFs or ISFs available. This suggests a large role for detailed, high spatial frequency information in the accurate identification of facial expressions of emotion, especially when display times are relatively long. The pilot experiment suggested that spatial frequency filtering impacts emotion identification accuracy and the perception of emotional valence and arousal. In all experiments, we found that LSF filtering blunts ratings of emotional arousal and pushes emotional valence toward neutral (compared to ISF and HSF filtering); both arousal and valence judgments may rely on details (e.g., wrinkles around the eyes, nose, and mouth) that are lost because of LSF filtering.

Further, our analyses of participants' sensitivity revealed dissociable patterns when participants were asked to categorize the emotional displays. While prior research has focused on the often-accurate detection of fearful faces in subpar viewing conditions (e.g., Goffaux et al., 2003; Stein et al., 2014), our data suggest that this may not be so straightforward. Specifically, we find that fear identification was impaired relative to perceptions of anger (pilot) and joy (pilot and Experiment 3). That is, both approach-motivational directed and positive emotions evidence enhanced perceptibility relative to fear. This pattern is consistent with previous research that suggests that happy faces are identified quicker and easier (Srivastava & Srinivasan, 2010), and may rely more on global (vs. local) processing and therefore require fewer visual resources to identify (Srinivasan & Hanif, 2010). In contrast, the discrimination between emotions that are

conceptually similar (e.g., fear and surprise) may require more local processing, or bodily cues to accurately identify those emotional displays (e.g., Aviezer et al., 2012). Indeed, our data suggest that high spatial frequency information—information that requires more local processing and attentional resources (Srinivasan & Hanif, 2010)—increases sensitivity to detect differences between fear and surprise relative to low spatial frequency information. Altogether, these findings suggest that emotional expressions, spatial frequency content, and the broader context (i.e., detecting fear among negative emotions or among positive emotions) each have important influences on the accurate categorization of emotional expressions.

Our findings are consistent with previous research that suggests the identification of discrete emotions is most accurate for emotions intended to convey meaning across people (Martinez & Du, 2012). The identification of emotion is sensitive to the type of content being conveyed and its functional significance. For example, previous research found that happiness—a globally processed emotion that is intended to convey information to others—was most accurately identified at farther distances (Smith & Schyns, 2009). While we did not directly manipulate viewing distance in the present experiments, our low spatial frequency findings support that people are highly accurate identifiers of joyful and happy states. Interestingly, Smith and Schyns (2009) point out that anger was poorly identified at far distances, even though, like joy or happiness, there is utility in accurately identifying incoming threats at far distances or poor viewing conditions, and anger tends to be globally processed (like happiness; Clore & Martin, 2001; Clore & Huntsinger, 2007). However, our findings suggest that anger, when compared to other negative emotions, is easily identified. One reason for this discrepancy may be a function of the differences in tasks. Features outside of the visual or content information of an emotion shape the efficacy of its communication. For example, the nature of an experimental task shapes

how emotion expressions are identified (Smith & Merlusca, 2014). The present research required people to make identification decisions about anger in comparison to other negative emotions rather than discerning anger from emotions that vary in valence, which may have shifted the strategy of identification for participants.

These present findings also support a growing body of literature that suggests the identification of fearful facial expressions is more difficult and may rely less on low-pass information than previously thought (e.g., Martinez & Du, 2012; Smith & Merlusca, 2014). Instead, the identification of fearful expressions, like many other visual phenomena, is highly context dependent and shaped by the comparison group. When emotional expressions are subset into smaller groupings (e.g., fear vs. neutral), patterns of identification differ compared to when they are in larger groupings (e.g., fear, happiness, sadness, surprise; Smith & Merlusca, 2014). Here, we demonstrate that when emotion identification is in reference to emotions that are matched on valence, sensitivity for identification of fearful facial expressions was highest, and when matched on arousal, sensitivity for identification of joyous facial expressions was highest. Diminished visual input impedes the differentiating between emotions that are likely to cooccur in contexts together.

Moreover, these results also illustrate important social implications of decision making with degraded visual information. The ability to detect emotions is vital to properly functioning in the social world, but without contextual information (e.g., bodily cues), errors are common. We find that ratings of emotional arousal and valence are both truncated under poor visual conditions—a pattern which may have consequences for real life situations where visibility is low (Nyman et al., 2019), and we are at risk of encountering a threatening stimulus (or even limiting one's ability to offer aid to someone in need). In such situations, top-down contextual

information may have a strong influence on the ultimate categorization of an emotional expression, leading to both underestimations (e.g., pain; Mende-Siedlecki et al., 2019) and overestimations (e.g., anger and race; Hutchings & Haddock, 2008) based on identity. Our supplementary analysis adds to this result by illustrating that the strength of the effect differs across different emotion conditions. If one considers ISF to be the “default” way that faces are perceived, degrading the visual field information by removing spatial frequencies (or more realistically, reducing the available light or increasing the viewing distance) produces a blunted perception of that emotion’s arousal and valence. This effect occurs more strongly for anger and disgust, effectively rendering them indistinguishable from each other. This is critical – while both emotions suggest danger and motivate avoidance, the source of the danger differs meaningfully. An angry person approaching you may intend to attack, whereas a disgusted person approaching you may indicate the presence of an aversive, harmful stimulus in the environment. Similarly, Experiment 2 found a similar blunting effect for fearful and surprised targets, where again participants were largely incapable of distinguishing them on arousal and valence dimensions, despite differences in the motivation behind displaying a fearful versus surprised expression.

Limitations & Future Directions

One limitation to the present experiments is that emotional expressions were displayed as forward-facing static singletons. However, the process of detecting emotional signals is a fluid one that relies on distinct diagnostic features for different emotions. For instance, research that suggests somatic signals are important for transmitting emotional content (Aviezer et al., 2012), and context is crucial for understanding emotional states (Carroll & Russell, 1996; Barrett et al., 2011; see also Zebrowitz & Montepare, 2008). Future research should include dynamic and

naturalistic emotion stimuli (e.g., Van Der Zant & Nelson, 2021) to better understand the types of information that scaffold accurate emotion identification. Additionally, we used forward-facing emotional expressions, but differences in intensity of facial expression, gaze, and head turn may also influence accuracy of emotional expression categorization and have led our stimuli to be more ambiguous emotional cues than are typically encountered. For example, while the eyes tend to inform decoding of emotions like fear and anger (Smith et al., 2005) and other important cues (e.g., Adolphs et al., 2005; Tomasello et al., 2007), the mouth is also heavily relied on for understanding expressions such as disgust (Chapman et al., 2009), joy, and surprise (Smith et al., 2005). When facial expressions do not well map onto the other subtle cues of emotional expression (e.g., eye-gaze, body posture), or portions are obfuscated, these signals become noisier, which may have additional consequences for accurate identification of emotion expressions. For instance, laboratory presentations of fear signals are often ambiguous because a congruent fear expression requires that eye gaze be averted (as opposed to direct). Thus, when encountering a facial expression of forward facing, direct eye-gaze fear, the typically encountered signature of that expression is less cogent, leading to diminished detection accuracy (Adams & Kleck, 2003; Im et al., 2017; Sato et al., 2004). The effects of introducing noise to facial expression decoding can also be seen in recent research that suggests wearing a mask (hiding signal from the mouth) diminishes individuals' reliance on arousal cues (Barrick et al., 2020). Future research should investigate how obfuscation of face parts, gaze, and head positioning influence accuracy of emotional expression identification when only low or high spatial frequency information is available. Finally, while not central to our hypotheses, we conducted simple effects tests for the arousal, valence, and sensitivity dependent variables in Experiments 1 and 2. These effects explored by-emotion differences at each level of spatial

frequency filtering, ultimately finding a differential boost effect for some emotions (e.g., anger and fear in Experiment 1; joy in Experiment 2). Future research should more directly test whether motivational direction also interacts with spatial frequency filtering when exploring emotion detection.

Another limitation comes from the design of the experiments. First, these data were collected online and thus could not control for viewing distance or lighting (both of which influence the information available to the retina). However, in light of our findings supporting patterns seen in previous work (e.g., Smith & Schyns, 2009), and other research that has used similar online methodology to examine the effects of spatial frequency filtering on emotion perception (Cassidy et al., 2021), we do not believe this is a major concern for interpreting these findings. Future research should directly compare online to in-lab spatial frequency experiments to gain a better understanding of the sensitivity of these effects to minor environmental differences. Second, because these experiments were all within-subjects designs, there may have been emotional aftereffects (i.e., the perception of an emotional face stimulus imprints and influences a participant's downstream perception of a different face stimulus) or anchoring that influenced perception of differing emotional categories. For instance, research on emotion aftereffects has found that angry but not happy faces presented in LSFs evidence aftereffects, but that aftereffects persist for all faces presented in HSFs (Prete et al., 2018). Moreover, Laeng et al. (2010) explored similar emotional biasing effects, presenting participants with face morphs that overlaid an emotional LSF face onto a neutral HSF face, asking them to rate such targets on friendliness. They found the emotional content in the LSF faces significantly biased participants' impressions in the direction of that "invisible" target's affective display, illustrating a putative role for LSF information to have a subliminal biasing effect that does not reach conscious

awareness. However, we fully randomized stimulus presentation in our experiments so are not at risk of any systematic aftereffects confounding our results. Nevertheless, future research could employ back-masking to avoid any risk of afterimages introducing extraneous variance.

Finally, as noted above, task constraints also affect the emotional expression identification process. Research suggests that emotion identification tasks with binary (emotion vs. neutral) categories rely more flexibly on low spatial frequency information compared to multiple categories (Smith & Merlusca, 2014). This may help explain why we did not find any advantage for fear in the low spatial frequency domain across experiments. Each experiment tested emotion identification for a series of multiple emotions that share an affective feature (either valence or arousal). This context may have led to reliance on HSF cues to discern between the key visual features of the differing emotion, leading to a drop in the accuracy of fear and reliance on LSF information.

Conclusion

Across one pilot and two experiments, we found that removing high spatial frequency information reduced negativity and arousal ratings, and diminished emotion categorization accuracy. Overall, the results advance the literature on how dissociable spatial frequency bands shape the processing and interpretation of emotional expressions. In the current work, we additionally incorporated systematic manipulations of the valence, functional significance, and arousal level of the facial displays, integrating work on the visual decoding of expression with theories on the structure and interpersonal implications of emotional experiences. Collectively, these results are informative for both visual science and social cognitive research on emotional expressions.

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