**Object Clusters or Spectral Energy? Assessing the Relative Contributions of
Image Phase and Amplitude Spectra to Trypophobia**

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Abstract

Trypophobia refers to the visual discomfort experienced by some people when viewing clustered patterns (e.g., clusters of holes). Trypophobic images deviate from the $1/f$ amplitude spectra typically characterizing natural images by containing excess energy at mid-range spatial frequencies. While recent work provides partial support for the idea of excess mid-range spatial frequency energy causing visual discomfort when viewing trypophobic images, a full factorial manipulation of image phase and amplitude spectra has yet to be conducted. Here, we independently manipulated the phase and amplitude spectra of 31 Trypophobic images using a standard Fast Fourier Transform (FFT). Participants rated the four different versions of each image for levels of visual comfort, and completed the Trypophobia Questionnaire (TQ). Images having the original phase spectra intact (with either original or $1/f$ amplitude) explained the most variance in comfort ratings and were rated lowest in comfort. However, images with the original amplitude spectra but scrambled phase spectra were rated higher in comfort, with a smaller amount of variance in comfort attributed to the amplitude spectrum. Participant TQ scores correlated with comfort ratings only for images having the original phase spectra intact. There was no correlation between TQ scores and comfort levels when participants viewed the original amplitude / phase-scrambled images. Taken together, the present findings show that the phase spectrum of trypophobic images, which determines the pattern of small clusters of objects, plays a much larger role than the amplitude spectrum in determining visual comfort.

Keywords: *Trypophobia, Visual discomfort, Fourier analysis, Phase spectrum, Amplitude spectrum*

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Introduction

Trypophobia is a recently documented perceptual phenomenon characterized by extreme discomfort when viewing repetitive clusters of objects, usually holes or bumps (Cole & Wilkins, 2013; Le, Cole & Wilkins, 2015). An example of a trypophobic image is shown in Fig. 1a (top left). Only a minority of individuals seem to qualify as being trypophobic (roughly 15 to 17%, Cole & Wilkins, 2013; Pipitone, Gallegos & Walters, 2017), and its status as a clinical phobia has yet to be determined by the Diagnostic and Statistical Manual of Mental Disorders (APA, 2013; Can, Zhuoran & Zheng, 2017). Nevertheless, many non-trypophobic individuals (Cole & Wilkins, 2013; Kupfer & Le, 2017; Pipitone et al., 2017), including children (Can, Zhuoran & Zheng, 2017) report experiencing some level of discomfort when viewing trypophobic images.

Two main theoretical frameworks have been proposed to explain trypophobia (Cole & Wilkins, 2013; Kupfer & Le, 2017; Yamada & Sasaki, 2017); both theories suggest that the visual discomfort elicited by trypophobic stimuli is an evolved response to help organisms detect and avoid harmful stimuli. One proposal is that the characteristic trypophobic patterns contain excessive energy at mid-range spatial frequencies, as defined in previous work (Sasaki et al. 2017: 2-9 cycles per degree of visual angle (cpd); Fernandez & Wilkins 2008: 3 cpd +/- 2 octaves). This same spectral energy profile can also be observed in the patterning of many venomous and/or predatory animals like snakes and spiders (Cole & Wilkins, 2013). In contrast, an alternative theory proposes that the aversion to clusters of roughly circular shapes represents a response that helps

organisms avoid parasitism and infectious disease (Kupfer & Le, 2017). Both of these theoretical frameworks assume that viewing discomfort stems from patterns that contain high contrast energy at mid-range spatial frequencies. However, several recent findings raise the possibility of other interpretations. Using image filtering techniques, Sasaki et al (2017) showed that low to mid-range spatial frequencies in trypophobic images invoked the most discomfort, comparable to the original images, but specifically filtering mid-range spatial frequencies did not reduce visual discomfort. What is more, this study did not account for the image phase spectrum. Le et al. (2015) filtered trypophobic images to have a $1/f$ natural image spectra, thus removing the excess mid-range energy, and found that those images continued to invoke visual discomfort. Using a continuous flash suppression technique to measure access to early visual awareness, Shirai & Ogawa (2019) recently showed that trypophobic images enter visual awareness earlier than fearful or neutral images, but a second experiment in which these images were phase-scrambled (but the original amplitude spectrum was left intact) mitigated the early awareness effect. These recent findings suggest that the energy spectra of trypophobic images may not be solely responsible for evoking visual discomfort.

Present study

This study seeks to better understand the relationship between the spectral components of trypophobic images and their relation to visual comfort. Using Fourier analysis, the phase and amplitude spectra of trypophobic images were independently manipulated in a factorial design to assess the unique aspects of each on levels of visual comfort. Using the Trypophobia Questionnaire (TQ), we also investigated how a

participant's level of tryphobia influenced the levels of image comfort across all image manipulations.

Methods

Images and image manipulation

Thirty one tryphobic images (T1-T31) were used in this study. Some images were obtained from websites devoted to tryphobia (e.g., <https://tryphobia.com/>), while other images were provided by Arnold Wilkins and were used in Cole & Wilkins (2013) and Pipitone et al. (2017). All images were cropped to minimize non-tryphobic background imagery, resized to 512 x 512 pixels, converted to grayscale, scaled to 25% RMS contrast, and saved as 8-bit BMP files. The complete set of images is available for download at: <http://itech.fgcu.edu/faculty/cdimattina/resources.html>.

In order to independently manipulate the phase and amplitude spectra of the images, we employed the standard 2-D Fast Fourier Transform (FFT) implemented in MATLAB® (R2015a) as `fft2.m`. Fourier image analysis makes use of the mathematical fact that every image can be exactly reconstructed using a weighted linear sum of sinusoidal plane waves having varying orientations, spatial frequencies and phases. The set of weights applied to each plane wave for a given image are collectively known as the *amplitude spectrum*, and the phases of each plane wave are known as the *phase spectrum*. Therefore, we can equivalently characterize an image in either the space domain (pixel values) or the frequency domain (amplitude and phase spectra), using the FFT and the inverse FFT to map between the two (Gonzales & Woods, 2017). The amplitude spectra defines which spatial frequencies are present in an image, and the phase spectrum determines where the waves interfere constructively and destructively to create localized

features like edges or texture elements (Oppenheim & Lim, 1981; Tadmor & Tolhurst 1993; Wichmann, Braun, & Gegenfurtner 2006). Therefore, by manipulating the phase spectrum while leaving the amplitude spectrum intact, we can create an image with the same spatial frequency content as a tryphobic image, but with but no localized visual patterns like holes or bumps. Conversely, by manipulating the amplitude spectrum while leaving the phase spectrum intact, we can create images with a $1/f$ amplitude typical of most natural images (Field, 1987; Ruderman & Bialek, 1994) but having the same clustered object pattern as tryphobic images. Hence, we can dissociate the clustered pattern from the amplitude spectrum to evaluate their relative contributions to visual discomfort.

Fig. 1a illustrates our manipulations of one of the tryphobic images (T4). The original image can be found in the top left corner of Fig. 1a. By randomizing the phase spectrum while preserving the original amplitude spectrum, we produce the phase-scrambled image (Fig. 1a, top right). Note that while this image has the same spatial autocorrelation structure as the original, it does not have the fine edge structure which defines the clustered pattern of holes in the original. As we see in Fig. 1b, this phase-scrambled image has an identical amplitude spectrum to the original image (blue curves in both panels), with both images containing an excess of mid-range spatial frequency energy relative to $1/f$ (Fig. 1b, red curves). Conversely, we can take the original image and set its amplitude spectrum to the $1/f$ spectrum typical of natural images. This produces the image in the lower left of Fig. 1a, which contains the fine structure of the original, including the holes, but has a somewhat “washed out” appearance. Finally, as a control stimulus, we also present $1/f$ noise (Fig. 1a, bottom right) which has a naturalistic

138 amplitude spectrum and also a randomized phase spectrum. Collectively, this set of
 139 images defines a 2 x 2 factorial design where the first factor is the amplitude spectrum
 140 (original or 1/f) and the second factor is the phase spectrum (original or scrambled).

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142 **Figure 1:** Factorial manipulation of amplitude and phase spectra for a representative
 143 trypophobic image. (a) *Top left:* The original image. *Top right:* Original amplitude
 144 spectrum, scrambled phase spectrum. Note the absence of fine edge structure needed to
 145 define holes. *Bottom left:* Original phase spectrum, 1/f amplitude spectrum. Note the
 146 holes are still clearly visible, but have lower contrast. *Bottom right:* 1/f noise. (b) *Left:*
 147 Rotational average of the amplitude spectra of the original image (blue) and original
 148 phase / 1/f amplitude image (red line) shown in (1a). *Right:* Rotational average of the
 149 amplitude spectra of the original amplitude/ scrambled phase (blue) and 1/f noise (red)
 150 images shown in (1a).

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In order to verify that the 31 Trypophobic images in our set contain excess spectral energy (relative to $1/f$) in mid-range spatial frequencies, for each image we computed the proportion of total stimulus energy in each of the two mid-range spatial frequency bands defined previously (Sasaki et al. 2017: 2-9 cpd; Fernandez & Wilkins 2008: 3 cpd $\pm$ 2 octaves, or 0.75-12 cpd). We then computed the proportion of stimulus energy in these same frequency ranges for $1/f$ images, and took a ratio ρ of the proportions computed for our tryophobic images to those computed for the $1/f$ images. A ratio $\rho > 1$ represents excessive mid-range spatial frequency energy with respect to $1/f$. As we can see from the histograms in Fig. 2, for both definitions of mid-range spatial frequencies, the overwhelming majority of the images in our set have a greater proportion of energy in these ranges than $1/f$ images. For the 2-9 cpd definition (Sasaki et al. 2017), we see in Fig 2a that 27/31 images have a $\rho > 1$, with median $\rho = 1.67$ ($Q_1 = 1.27$, $Q_3 = 1.92$) significantly greater than unity ($p < 0.001$, Wilcoxon sign-rank test, $N = 31$). Likewise, for the 3 cpd $\pm$ 2 octaves (or 0.75-12 cpd) proposed by Fernandez & Wilkins (2008), we see in Fig. 2b that 24/31 images have $\rho > 1$, with median $\rho = 1.40$ ($Q_1 = 1.01$, $Q_3 = 1.75$) significantly greater than unity ($p < 0.001$, Wilcoxon sign-rank test, $N = 31$). Across the set of images we find a significant positive correlation between the values of ρ obtained from the two definitions of mid-range spatial frequencies ($r(31) = 0.67$, $p < 0.001$), with the value measured using one definition accounting for about 45% of the total variance in the value measured with the other definition ($r^2 = 0.449$).

Figure 2: Ratio of the mid-range spatial frequency (SF) energy in our 31 images relative to energy in the same SF range in images with $1/f$ spectra, for two different definitions of mid-range SF. A ratio greater than unity indicates excess energy in this range relative to $1/f$. (a) Mid-range SF defined as 2-9 cycles per degree of visual angle, as in Sasaki et al. (2017). (b) Mid-range SF defined as 3 cpd, $\pm$ 2 octaves (0.75-12 cpd), as in Fernandez & Wilkins (2008).

Participants

One hundred and forty seven undergraduate students (34 male, 113 female) ranging from 18 to 30 years in age ($M = 19.65$, $SD = 2.15$, with 7 not reporting age) were recruited from the institution's General Psychology research pool (Sona-Systems®, <https://www.sona-systems.com/>) for class credit or from other classrooms for extra credit. All participants reported having normal or corrected-to-normal vision.

Procedure

Participants used the online survey Checkbox® (<https://www.checkbox.com/>) to answer several demographic questions (e.g., history of psychological disorders, any medication, normal vision) and the GAD-7 for generalized anxiety levels (Spitzer, Kroenke, Williams, & Lowe, 2006). Then, participants viewed two alternating tryphobic images on another computer monitor (lotus seedpod and honeycomb) and completed the Trypophobia Questionnaire (TQ; Le et al, 2015) which has 17 items

assessing various emotional reactions to the images (e.g., feel nervous, feel sick or nauseous, feel skin crawl) on a 5-point Likert scale (ranging from not at all to extremely). Responses to both the GAD-7 and TQ were summed to create aggregate levels of anxiety and trypophobia, respectively. Participants then viewed the original and three different manipulated versions of 31 trypophobic images on one computer (4 stimuli for each original image: see Fig. 1) and were given 7 seconds for each stimulus to rate their level of visual comfort on a scale of -5 (extremely uncomfortable) to 5 (extremely comfortable) using Checkbox® survey software running on another computer. Since different instantiations of the stimuli having randomized phase spectra yield non-identical images, the first 20 participants viewed two different versions of the phase-scrambled and 1/f noise images (Fig. 1a, right column), for a total of 6 stimuli per original image.

Previous work on trypophobia has used highly variable visual displays and has presented images at a variety of spatial scales (Cole & Wilkins, 2013; Le et al, 2015; Sasaki et al., 2017). Given the average size and periodicity of the clusters in our images, and the size of the images on the monitors, viewing distance from the monitors was chosen so that the images subtended four degrees of visual angle (dva). This focused the excess spectral energy for each image in roughly in the same range (~3 cpd) described previously as inducing discomfort (Cole & Wilkins, 2013; Fernandez and Wilkins, 2008; Sasaki et al., 2017). In addition, since previous work has not systematically investigated whether monitor gamma calibration affects trypophobic responses, we ran our tests on both an uncalibrated LCD monitor (91 participants) and two different gamma-corrected CRT monitors (56 participants). The uncalibrated LCD monitor was a Dell P2213 (22", 1680 x 1050), viewed at a distance of 158 cm. Images on this set-up were presented as a

slide-show using PowerPoint®. Two different gamma-corrected ($\gamma = 1.0$) monitors driven by a Bits# stimulus processor (Cambridge Research) were employed. The first gamma-corrected setup was a ViewSonic® Optiquest Q71 (17", 1024x768, 75 Hz) with midpoint luminance of 52.2 cd/m². Images were scaled to 256x256 and viewed at a distance of 108 cm. The second gamma-corrected setup was a SONY FD-500 Trinitron (21", 1024x768, 75 Hz) having midpoint luminance of 35.6 cd/m². Images were scaled to 256x256 and viewed at distance of 143 cm. Stimulus presentation for both of these calibrated setups was controlled by a custom MATLAB® script employing PsychToolbox-3 routines (Kleiner, Brainard & Pelli, 2007)..

Results

Data were analyzed using the GLM procedure in SPSS® version 24.0 (IBM). Twenty seven participants (18.4%) reported suffering from a clinical psychological disorder (e.g., depression, anxiety, comorbid depression and anxiety). Of these participants, 13 were currently using medication. Exclusion of these participants did not change any of the results, thus they were included in all subsequent analyses.

Effects of phase and amplitude on comfort levels

Figure 3 shows the average comfort ratings for each of the four image conditions (Fig. 1a) for all participants. A 2 (phase condition: original vs. scrambled) x 2 (amplitude condition: original vs. $1/f$) repeated measures factorial ANOVA was performed to examine the unique impact of phase and amplitude on levels of visual comfort. There was a significant main effect of the phase spectrum on visual comfort, $F(1,146) = 48.39$, $p < .001$, $\eta^2 = .249$. Participants rated the original-phase images lower in visual comfort than the scrambled-phase images. There was also a significant main effect of the amplitude

spectrum on visual comfort, $F(1,146) = 14.51$, $p < .001$, $\eta^2 = .09$. As shown in Fig. 3, average comfort ratings were lower for the original-amplitude images compared to the $1/f$ amplitude images. There was also a significant interaction of the phase and amplitude spectra on visual comfort, $F(1,146) = 9.54$, $p = .002$, $\eta^2 = .061$. Participants gave slightly lower comfort ratings to the scrambled phase / original amplitude images than the scrambled phase / $1/f$ images, but there was little difference between the ratings given to the original images and the original phase / $1/f$ amplitude images.

Figure 3: Mean comfort levels across all 31 tryphobic images (and their 3 manipulated versions) for all 146 participants (error bars represent 95% confidence intervals). The main effect of phase explained the most variance in visual comfort (24.9% variance explained), followed by the main effect of amplitude (9% variance explained), followed by the interaction of phase and amplitude (6.1% variance explained).

Controls for noise instance and gamma correction

In order to assess whether our effects were consistent across different instantiations of the random phase spectra used to generate the scrambled phase and $1/f$ noise conditions, the first 20 participants viewed two different scrambled phase (Fig. 1a, top right) and $1/f$ amplitude (Fig. 1a, bottom right) images per original tryphobic image (for a total of 6 stimuli per original image rather than 4). Using the images as the level of analysis (each image was rated by 20 participants), two paired-sample t tests showed that levels of visual comfort were not significantly different across all of the first vs. second scrambled phase manipulated images, $t(30) = -.751$, $p = .459$, or the first vs. second $1/f$ amplitude images, $t(30) = -.289$, $p = .774$. Using the raters as the level of analysis across all 62 image types, paired sample t -tests between all of the 31 first vs. second scrambled phase and 31 first vs. second $1/f$ amplitude images revealed only 1 significant difference in visual comfort (image T30 for first vs. second $1/f$ amplitude), but this is well within the range of the expected Type I error inflation from running 62 tests. We conclude that no manipulation effects were evident when constructing the scrambled phase and $1/f$ amplitude images, hence the full analysis only used the first generated scrambled phase and $1/f$ amplitude image.

We also assessed whether responses would change as a function of monitor gamma correction, an issue that has not been explored previously. Using a mixed-model factorial ANOVA with monitor type as a between-subjects factor, the main effect of monitor type alone did not influence levels of visual comfort, $F(1,145) = 2.193$, $p = .141$, $\eta^2 = .015$. The three-way interaction of phase, amplitude, and monitor type on levels of comfort was also not significant, nor were the two-way interactions of phase and monitor

type or amplitude and monitor type, all F 's < 1.928 , $p > .167$, $\eta^2 < .013$). We conclude that our observed effects of amplitude and phase spectra on visual comfort are robust to the gamma nonlinearity present in standard commercial displays (Lu & Doshier, 2013). Therefore, for all other analyses reported here we pooled the data across both gamma calibrated and un-calibrated setups.

TQ scores, phase and amplitude on comfort levels

Participants filled out the Trypophobia Questionnaire (TQ), in order to assess whether levels of tryphobia would affect ratings of visual comfort as a function of image phase and amplitude spectra. Eleven participants had scores higher than 31 (7.4%) and would be considered tryphobic (Le et al., 2015) which is a smaller proportion than what others have reported in their samples (Cole & Wilkins, 2013; Pipitone et al., 2017). Following Sasaki et al. (2017), we ran analyses on participants who scored in the top and bottom third (33%) of the TQ. As a result, 49 participants were in the high Trypophobia condition (HTRY) and 49 were in the low tryphobia condition (LTRY). Three participants had outlier raw TQ scores ($Z > 3.33$) however their comfort ratings were not outliers, hence their data is retained in this analysis (see later analyses for their exclusion). Using a mixed-model factorial ANOVA with TRY scores as the between-subjects factor, the main effect of TRY scores did influence levels of visual comfort, $F(1,96) = 17.63$, $p < .001$, $\eta^2 = .155$. HTRY participants had lower levels of visual comfort than LTRY participants, which is to be expected. The three-way interaction of phase, amplitude and TRY scores was not significant, $F(1,96) = 2.89$, $p = .092$, $\eta^2 = .029$. However the two-way interaction of phase and TRY scores on levels of comfort was significant $F(1,96) = 54.17$, $p < .001$, $\eta^2 = .361$. As seen in Fig. 4a, LTRY participants

did not differ in their comfort scores when viewing original or scrambled phase images,
 collapsed across the amplitude condition, but HTRY participants had much lower
 comfort levels when viewing the original phase images compared to the scrambled phase
 images, collapsed across amplitude condition. The two-way interaction of amplitude and
 TRY scores on levels of discomfort was also significant $F(1,96) = 8.477, p = .004, \eta^2 =$
 .081. As seen in Fig. 4b, LTRY participants did not differ in their comfort level when
 viewing original or 1/f amplitude images, collapsed across the phase condition, but
 HTRY participants had slightly lower levels of comfort when viewing the original
 amplitude images compared to the 1/f amplitude images, collapsed across the phase
 condition.

Figure 4: Interactions between TQ scores and the phase spectra (a) and TQ scores and the amplitude spectra (b) on levels of comfort. The TQ by phase interaction was the largest effect, explaining 36.1% of the variance in comfort levels. The TQ by amplitude interaction explained 8.1% of the variance in comfort levels. Participants who scored high on the TQ rated images with the phase spectra intact much lower in comfort (a), compared to other conditions. Error bars represent 95% confidence intervals.

Correlations between TQ Scores and Visual Comfort across the Four Different Image Conditions

In order to further investigate the effects of phase and amplitude spectra on visual comfort, correlation analysis was used to assess the relationship between participant's TQ scores and their averaged level of comfort ratings for all image conditions. Three participants had outlier raw TQ scores ($Z > 3.33$), and were thus excluded from this analysis to be conservative (this did not affect results). Across the 144 participants, TQ scores were significantly negatively correlated with the original tryphobic image comfort levels, $r(144) = -.53, p < .001$ (Fig. 5, top left). This demonstrates validity of the TQ and replicates previous work (e.g., Le et al., 2015; Pipitone et al., 2017). TQ scores were also significantly negatively correlated with participants' averaged comfort level for the original phase / $1/f$ amplitude images, $r(144) = -.485, p < .001$ (Fig. 5, bottom left). However, TQ scores were not significantly correlated with participant's averaged comfort level for the scrambled phase / original amplitude images, $r(144) = -.064, p = .448$ or the scrambled phase / $1/f$ amplitude images, $r(144) = -.031, p = .716$ (Fig. 5, top and bottom right, respectively). Results from these analyses are summarized in Table 1.

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343 **Figure 5:** Correlations between scores on the TQ and average comfort levels for the four
 344 different image conditions. *Top left:* TQ scores correlated significantly with original
 345 tryphobic image comfort levels. *Bottom left:* TQ scores correlated significantly with
 346 original phase / 1/f amplitude image comfort levels. *Top right:* TQ scores were not
 347 correlated with scrambled phase / original amplitude image comfort levels. *Bottom right:*
 348 TQ scores were not correlated with scrambled phase / 1/f amplitude image comfort
 349 levels.

350

351 Table 1.

352 *Correlations between averaged participant comfort levels given to the four image conditions and scores on the Trypophobia*
 353 *Questionnaire (TQ), scores from the bottom 33% (LTRY) and top 33% (HTRY) of the TQ.*

Comfort levels and TQ scores – Participant as level of analysis

Image Variable Comfort Level	TQ (N=144)	LTRY (N=144)	HTRY (N=144)
Original Phase / Original Amplitude	-.53**	.044	-.532**
Original Phase / 1/f Amplitude	-.485**	.098	-.488**
Scrambled Phase / Original Amplitude	-.064	.09	-.116
Scrambled Phase / 1/f Amplitude	-.031	.098	-.061

354 ** $p < .001$

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We also found no significant correlation between GAD-7 and TQ scores, $r(144) = .012, p = .886$. This replicates previous work showing that at among the general population, tryphobia does not seem to simply be a manifestation of generalized anxiety (Le et al., 2015; Pipitone et al., 2017; but see Vlok-Barnard & Stein (2017) for the comorbid relationship between tryphobia, depression and anxiety among tryphobic individuals).

To investigate how these results relate to participant's TQ scores, we ran the same analyses described above on LTRY and HTRY participants. Among LTRY participants, TQ scores were not significantly correlated with original tryphobic image comfort levels, $r(49) = .044, p = .766$, comfort levels for the original phase / $1/f$ amplitude images, $r(49) = .098, p = .505$, comfort levels for the scrambled phase / original amplitude images, $r(49) = .090, p = .540$, or the scrambled phase / $1/f$ amplitude images, $r(49) = .098, p = .504$. Among HTRY participants, TQ scores were significantly correlated with original tryphobic image comfort levels, $r(46) = -.532, p < .001$, and to the comfort levels for the original phase / $1/f$ amplitude images, $r(46) = -.488, p = .001$. Critically however, TQ scores and comfort levels were not significantly related to averaged comfort levels when viewing the scrambled phase / original amplitude images $r(46) = -.116, p = .444$, or the scrambled phase / $1/f$ amplitude images, $r(46) = -.061, p = .685$. These correlation analyses are summarized in Table 1.

Discussion

The current literature discusses tryphobic discomfort as stemming from excess energy at mid-range spatial frequencies (Cole & Wilkins, 2013; Sasaki et al., 2017), supporting other work showing that deviations from natural $1/f$ amplitude spectra affects visual comfort (Fernandez & Wilkins, 2008; Juricervic et al., 2010; O'Hare & Hibbard, 2011; Hibbard & O'Hare 2015). While these studies measure (Cole & Wilkins, 2013) or filter (Le et al., 2015; Sasaki et al., 2017) the amplitude spectrum of tryphobic images, the phase component was not manipulated or controlled systemically. The present study is the first to use Fourier analysis on tryphobic images to independently manipulate the phase and amplitude spectra in order to understand their relative contributions to visual comfort levels. Our analyses clearly demonstrate that the phase spectrum plays a larger role in affecting viewer's comfort than the amplitude spectrum (Fig. 3). The main effect of phase (whether there were clustered images present or not) explained 24.9% of the variance in participant's level of visual discomfort, while the main effect of amplitude (excess energy at mid-range spatial frequencies) played a smaller role, explaining 9% of the variance in visual comfort. The interaction of phase and amplitude on levels of visual discomfort was also significant, but only explained 6.1% of the variance in comfort levels. In other words, although the excess mid-spatial frequency energy in tryphobic images plays some role, the phase-dependent aspects (i.e., clusters of small objects, typically holes) played a much larger role.

In exploring how levels of tryphobia would affect results, we observed that participants who scored in the top third of the TQ (HTRY) rated the original phase spectra images much lower in comfort than the phase scrambled images, but comfort

ratings were comparable for both original and phase scrambled images among participants in the bottom third of the TQ (LTRY) (Fig. 4a). As seen in figure 4b, HTRY participants rated the original amplitude images lower in comfort compared to $1/f$ images, while LTRY participants rated original and $1/f$ images similarly. The TQ by phase interaction explained 36% of the variance in comfort ratings, while the TQ by amplitude interaction explained 8.1% of the variance, again showing the larger impact of the phase spectra on comfort ratings, particularly for individuals who score high on the TQ.

In addition, scores on the full range of the TQ were used to investigate its relationship with visual comfort when viewing the four different image manipulation conditions. Our results demonstrated a strong negative correlation between comfort levels and TQ scores when viewing the original phase and amplitude images and when viewing the original phase / $1/f$ amplitude images (Fig. 5, left two panels). However, there was no correlation between comfort levels and TQ scores when participants viewed the phase-scrambled / original amplitude images or phase-scrambled / $1/f$ amplitude images (Fig. 5, right two panels). What is more, among LTRY individuals, there was no significant relationship between TQ scores and comfort levels in any image condition. Even among HTRY individuals, significant relationships only existed with the images that depicted the image phase structure; TQ scores and comfort levels to images comprising the original amplitude but scrambled phase structure were not related to one another (see Table 1). In summary, these findings suggest that even among tryphobic individuals, those who score higher on the TQ did not find images with the original amplitude spectrum intact more uncomfortable to view.

Two current evolutionary frameworks exist to explain the manifestation of tryphobia. One view is that tryphobic images mimic the patterns found on dangerous animals, such as snakes and spiders. Thus, having a negative reaction to those specific patterns may provide a survival advantage (Cole & Wilkins, 2013). This view posits that tryphobia is a misfiring of an otherwise adaptive *fear* response. The other viewpoint considers tryphobia as an adverse negative reaction to clustered patterns on the surface of the skin stemming from parasites and infectious diseases. Thus, tryphobia may be an exaggerated and overgeneralized, albeit adaptive response to avoid contact with diseased individuals (Kupfer & Le, 2017), with this viewpoint positing that tryphobia encompasses more of a *disgust* response. Recent work seems to support the latter infectious disease / disgust response. For example, Imaizumi et al. (2016) show a positive relationship between TQ scores core disgust sensitivity. Kupfer and Le (2017) found that tryphobic individuals reported more disease-relevant pathogen avoidance remarks in open-ended questions when viewing tryphobic images. Yamada and Sasaki (2017) also showed that individuals with previous skin-related medical problems reported higher discomfort ratings towards tryphobic images compared to those who have no history of skin disease. Two other recent studies found greater unpleasantness ratings for faces of humans and animals when a tryphobic image (lotus seedpod) was superimposed on them compared to the tryphobic image viewed in isolation or when viewing the tryphobic image on inverted faces (Furuno et al., 2017; 2018). While the evidence seems to support the infectious disease / disgust response, previous work assumes excess energy at mid-range spatial frequencies to be the primary reason for visual discomfort, and our results show otherwise.

Some work has manipulated the phase and amplitude spectra of tryphobic images. Le et. al., (2015) removed excess energy from tryphobic images (giving them $1/f$ natural image spectra but kept the original phase spectra intact) and showed that tryphobic comfort was unaffected compared to the original images (even among tryphobic individuals). Shirai & Ogawa (2019) found that tryphobic images enter visual awareness sooner than fear-related and neutral images, but scrambled phase spectra of the same tryphobic images (leaving the original amplitude spectrum intact) mitigated the “pre-perceptual” processing effect. However, during “post-perceptual” processing, phase-scrambled images were rated more negatively than other image types. This latter result, along with the current findings seem to suggest that although excessive mid-range spatial frequency energy may invoke slightly more unpleasantness than would otherwise be the case (see Fig. 3), the excess energy has its largest effect on visual comfort through its interaction with the phase spectrum by enhancing the visibility of the clusters (compare Figs. 1a upper and lower left panels). In other words, the amplitude spectrum, in and of itself, does not invoke a strong tryphobic response (compared to what is seen when the natural phase spectrum is present).

The contextual features of tryphobic images need to be further investigated in order to gain a better understanding for their specific impact on visual comfort. For example, Le et al. (2015), showed no differences in visual comfort when viewing convex or concave images (i.e., bumps vs. holes) and suggest the “necessary but not sufficient” condition for unnatural image statistics to be the leading cause of tryphobia discomfort. Unfortunately, their image manipulations did not tease apart the phase and amplitude spectrum of the images, thus the amplitude properties were bound to the phase

components. But, those images did have an underlying commonality; all had clusters comprised of circular objects. Would there be differences in visual discomfort if the clusters were of non-circular objects? This phase specific aspect of tryphobic imagery might lend further credence to the parasitism model of infectious diseases, as many dangerous diseases (e.g., smallpox, typhus) involve clusters of roughly circular rashes or scabs on the skin (Kupfer & Le, 2017). What is more, the human visual system is sensitive to repetitive visual patterns (Conlon et al., 1999), thus visual discomfort stemming from tryphobic images might be a consequence of repetitive clusters of roughly circular objects, which invokes an adaptive disgust response.

Conclusions

Our findings show that while the current literature indicates excess energy at mid-range spatial frequencies as the defining feature of tryphobic images, our results suggest otherwise. The phase spectrum (independent of the amplitude spectrum) played a much larger role in determining comfort levels, compared to the amplitude spectrum (independent of the phase spectrum). While levels of tryphobia affected comfort levels attributed to images with the original phase spectrum intact, it played a negligible role in changing comfort levels as a function of image amplitude spectrum. Thus, the present study concludes that excess energy at mid-range spatial frequencies is neither a necessary nor a sufficient criterion for the induction of tryphobic discomfort.

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