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Trypophobic images induce oculomotor capture and inhibition

Risako Shirai[1] • Hayaki Banno[2] • Hirokazu Ogawa[1]

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Abstract
It is known that unpleasant images capture our attention. However, the causes of the emotions evoked by these images can vary. Trypophobia is the fear of clustered objects. A recent study claimed that this phobia is elicited by the specific power spectrum of such images. In the present study, we measured saccade trajectories to examine how trypophobic images possessing a characteristic power spectrum affect visual attention. The participants' task was to make a saccade in the direction that was indicated by a cue. Four irrelevant images with different emotional content were presented as periphery distractors at 0 ms, 150 ms, and 450 ms in terms of cue-image onset asynchrony. The irrelevant images consisted of trypophobic, fearful, or neutral scenes. The presence of saccade trajectory deviations induced by trypophobic images suggest that intact trypophobic images oriented attention to their location. Moreover, when the images were phase scrambled, the saccade curved away from the trypophobic images, suggesting that trypophobic power spectra also triggered attentional capture, which was weak and then led to inhibition. These findings suggest that not only the power spectral characteristics but also the gist of a trypophobic image affect attentional deployment.

Keywords Trypophobia · Saccade trajectory · Attention · Emotion

In everyday life, we select important information from complex visual scenes through attention. Due to the attentional process, salient objects are given high priority in the brain and are quickly detected. Threatening objects are generally deemed salient. From an evolutionary perspective, fast detection of threatening objects is of critical importance for survival (Kissler & Keil, 2008; Öhman, Flykt, & Esteves, 2001a). It is known that threatening cues in the environment receive priority in visual attention processing (Devue, Belopolsky, & Theeuwes, 2011; Fox, Russo, Bowles, & Dutton, 2001; LoBue & DeLoache, 2007; Nummenmaa, Hyönä, & Calvo, 2006; Öhman, Lundqvist, & Esteves, 2001b). Furthermore, recent studies have demonstrated that threat-related stimuli automatically capture attention and subsequently influence overt behavior (Schmidt, Belopolsky, & Theeuwes, 2012; Witt & Sugovic, 2013; but see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007).

A tremendous variety of factors elicit negative emotion; the causes of the emotion can vary. For example, negative emotions would be elicited by rotten foods that evoke thoughts of contamination, and by snakes that are potentially harmful. A fear of specific objects or situations is referred to as a "phobia." In the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 2013), a phobia is defined as a marked, persistent, and excessive or unreasonable fear when the individual is exposed to a specific object or situation. Although the criteria for a diagnosis of phobia are set out, identifying the etiology of the fear is difficult. For instance, some theories have attempted to explain phobias based on classical conditioning (e.g., Merckelbach & Muris, 1997) or evolutionary principles (e.g., Marks & Nesse, 1994). Based on classical conditioning, Merckelbach and Muris (1997) suggested that children with arachnophobia reported more aversive conditioning events with spiders than children without arachnophobia. However, such theories appear to have difficulty explaining all phobias, because there are some phobias that do not reflect potential objective danger from objects or situations. A case in point is trypophobia, which is a fear of particular clustered object configurations (Cole & Wilkins, 2013). For example, a lotus seed head can

✉ Risako Shirai
RisakoShirai@kwansei.ac.jp

[1] Department of Integrated Psychological Sciences, Kwansei Gakuin University, 1-155 Uegahara ichiban-cho, Nishinomiya-shi, Hyogo 662-0886, Japan

[2] Tokyo Metropolitan University, Tokyo, Japan

induce trypophobia. Although trypophobic images do not involve dangerous animals or the induction of a clear-cut frightening event, they can be a source of discomfort for many individuals.

Several studies have suggested a relationship between discomfort elicited by visual images and the Fourier power spectrum of the image (Cole & Wilkins, 2013; Fernandez & Wilkins, 2008; O'Hare & Hibbard, 2011; Wilkins et al., 1984). For example, Fernandez and Wilkins (2008) revealed that distressing images had greater Fourier power at midrange spatial frequencies than nondistressing images. Cole and Wilkins (2013) collected a variety of natural scene images, including trypophobic ones, to analyze their spectral characteristics. Most images depicting natural scenes are known to have visual components represented by a linear relationship (1/f slope): When the images are transformed into a sum of sine waves with different frequencies by a Fourier transformation, their log contrast energy is proportional to their log spatial frequency (Field & Brady, 1997). They found that trypophobic images showed relatively high-contrast energy at midrange spatial frequencies and suggested that trypophobic images induce discomfort because they have excess power energy at spatial frequency midranges, leading to a deviation from a linear relationship.

The purpose of the present study was to reveal how the spectral features of trypophobic stimuli affect the attentional system. To accomplish this purpose, we adopted a simple saccade task to measure saccade trajectories. Saccade trajectories are modified by the allocation of spatial attention during eye movements (McPeek, Han, & Keller, 2003; McPeek, Skavenski, & Nakayama, 2000; Van der Stigchel, Meeter, & Theeuwes, 2006; Van der Stigchel & Theeuwes, 2005). Several prior studies examined the modification of a saccade trajectory to reveal how threatening objects affect attentional processing (Nummenmaa, Hyönä, & Calvo, 2009; Petrova & Wentura, 2012; Schmidt et al., 2012; Weaver, Lauwereyns, & Theeuwes, 2011). The result patterns can be divided into two types: deviations toward or away from the location of a distracting object ("distractor"). In Schmidt et al.'s (2012) study, participants were required to make a saccade to a target in the direction indicated by an arrow cue while four irrelevant stimuli (one face and three objects) were presented at the periphery. Schmidt et al. demonstrated that the presence of angry faces caused saccadic eye movements to curve away from such stimuli, even though the faces were task irrelevant. They suggested that the curvature was due to inhibition at the location where the angry face was presented. The angry face possessed high emotional valence and therefore captured attention. To correctly saccade toward the target, the location of the face needed to be inhibited, resulting in curvature of the saccade trajectory. Conversely, McPeek et al. (2000) demonstrated that saccade trajectories deviated toward a distractor when the target and distractor colors were switched from trial to trial. From these studies, Van der Stigchel et al. (2006) argued that the deviations toward distractors were caused by unresolved competition between the target and the distractor. When the distractor captures attention too strongly, the distractor cannot be inhibited successfully, resulting in the saccades deviating toward the distractor.

In addition, we manipulated the power spectrum of trypophobic images utilizing the phase-scramble procedure, which changes the phase structure of an image but preserves other image characteristics such as spectral composition. A Fourier transformation converts an image to power spectra and phase spectra. Phase spectra determine image structures such as edges and curves (e.g., Banno & Saiki, 2015; Kovesi, 2000, 2003). By using this technique, we can examine the effect of the power spectrum of trypophobic images on attentional processing, independently of other information included in the image.

In the present experiment, participants were asked to make a saccade in the direction indicated by an arrow cue. During the saccade, four irrelevant natural images were presented. One of the irrelevant images was either trypophobic, fearful, or neutral, while the other images were task irrelevant neutral fillers. We measured curvature and endpoint deviation of saccades as the metrics of the inhibition toward the distractor, to examine the effect of trypophobic stimuli on oculomotor processing. In Experiment 1, we investigated whether intact trypophobic images as task-irrelevant distractors automatically influence the oculomotor system compared to fearful and neutral images. Furthermore, in Experiment 2, we presented phase-scrambled images (i.e., images having only power spectrum characteristics) and examined whether the power spectrum of a trypophobic image itself automatically influences the oculomotor system. If the characteristic power spectra of trypophobic images does influence the oculomotor system, image locations should be rapidly inhibited, resulting in saccades curving away from the location of trypophobic images compared to other images.

General method

Participants

Eighteen graduate and undergraduate students from Kwansei Gakuin University (one male and 17 females, mean age = 21.56 years) participated in Experiment 1, and 20 undergraduate students (six males and 14 females, mean age = 20.35 years) participated in Experiment 2 (four participated in both Experiments 1 and 2). All participants reported having normal vision and provided their written informed consent. The participants were seated 70 cm from a computer display with their chins positioned on a chin rest to fix their heads. Left eye movements were recorded using an EyeLink 1000 tracker

(SR Research Ltd, Canada) with a 1000-Hz temporal resolution.

Stimuli

In Experiment 1, distractor images consisted of 32 trypophobic, 32 fearful, and 32 neutral images. The trypophobic images consisted of clustered objects such as a lotus seed head (see Fig. 1a). The fearful images consisted of fear-inducing animals such as snakes. The neutral images were neutral scenes or objects (e.g., mountain scenery, kitchen tools, fruit). Stimuli were collected using Google image search. Some of the fearful and neutral images (see Appendix 1) were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). Moreover, 96 filler images were prepared to create a set of four irrelevant images with the distractor image. The filler images depicted neutral scenes or objects. All images were converted to grayscale, resized to 3.7° × 3.7°, and adjusted in mean intensity and root mean square contrast (RMS contrast) using the SHINE toolbox (Willenbockel et al., 2010) in MATLAB R2010a (MathWorks, Natick, MA).

Prior to the experiments, we confirmed the power spectrum of the images in the same way as Cole and Wilkins (2013). We applied a Hanning window to the images to remove edge effects, and the fast-Fourier-transform algorithm was applied to all images. Spatial frequencies were divided into bins, and the power spectrum of images summed in bins of spatial frequencies. Figure 2 shows the mean power spectra for each image type. We calculated the percentage variance of the power spectrum to confirm whether the power spectra of the images deviated from the 1/f natural slope. If the variance of the power spectrum is a low percentage, this means that the image power spectra do deviate from the 1/f slope and are therefore unusual natural images. A one-way ANOVA with factors of distractor image (trypophobic, fearful, or neutral) conducted on percentage variance revealed a main effect of distractor image, $F(2, 93) = 13.71$, $p < .001$, $\eta_p^2 = .23$. The percentage variance of trypophobic images (54.29%) was lower than that of fearful (72.82%), $t(93) = 23.16$, $p < .01$, $d = 0.71$, and neutral images (84.71%), $t(93) = 5.20$, $p < .001$, $d = 1.37$, and trypophobic images had an excess of a characteristic power spectrum compared to other images (4.00–5.66 and 11.31–32.00 cycles per image; cpi). These results are consistent with Cole and Wilkins (2013) in indicating that trypophobic images have unusual characteristic properties that other natural images do not possess.

For Experiment 2, phase-scrambled images were used as experimental stimuli (see Fig. 1b). To create the phase-scrambled images, the Fourier-transform-algorithm was applied to the original images. After the phase structures of the images were randomized, these randomized phase structures and the original power spectra were synthesized. Then, the inverse-Fourier-transform-algorithm was applied to the synthesized information and the phase-scrambled images were created. Through this procedure, the phase structure of the image was altered while other image characteristics were preserved. We created 32 phase-scrambled trypophobic images (PS-T images), 32 phase-scrambled fearful images (PS-F images), 32 phase-scrambled neutral images (PS-N images), and 96 phase-scrambled filler images.

Procedure

In both experiments, the participants engaged in a saccade task and an evaluation task.

Saccade task The saccade task consisted of a practice session and an experimental session. Each session started with a 9-point calibration procedure. Then, after a drift correction, each trial started with the presentation of an initial fixation cross (0.5° × 0.5°) at the display center and two markers (0.5° × 0.5°) at the bottom and top of the display. After the fixation cross was presented for a random time interval between 800 and 1,300 ms, the fixation was replaced by an arrow cue (1.5°), while the markers remained presented. The arrow cue directed the participant to either the top or bottom of the marker, and the directed marker indicated the target of the trial (see Fig. 3). The stimulus onset asynchrony (SOA) between the four irrelevant images and the arrow cue was manipulated to investigate the influence of time course on the image effects. The four irrelevant images (3.7° × 3.7°) were presented 450 ms before (450-ms stimulus onset asynchrony, SOA), 150 ms before (150-ms SOA), or simultaneously (0-ms SOA) with the arrow cue. In Experiment 1, one of the irrelevant images was a distractor image (trypophobic, fearful, or neutral image) and the others were filler images. In Experiment 2, one of the irrelevant images was a PS-T, PS-F, or PS-N image, while the other three images were phase-scrambled filler images. The distractor image was presented at the same frequency in every quadrant. Participants were asked to make a saccade toward the target as soon as the arrow cue was presented, ignoring the irrelevant images at the periphery. In half the trials, the participants needed to make a saccade toward the marker in the same hemifield as the distractor. In the other half, they had to make a saccade toward the marker in the opposite hemifield. The recording of eye movements and presentation of stimuli were controlled using the Psychtoolbox in MATLAB R2013b (Brainard, 1997; Pelli, 1997). The experimental session consisted of 2,160 trials, was divided into three or four segments, and followed 24 practice trials on each occasion.

Evaluation task After the saccade task, we conducted an evaluation task to measure the valence and arousal of all images using the affect grid method (Russell, Weiss, & Mendelsohn,

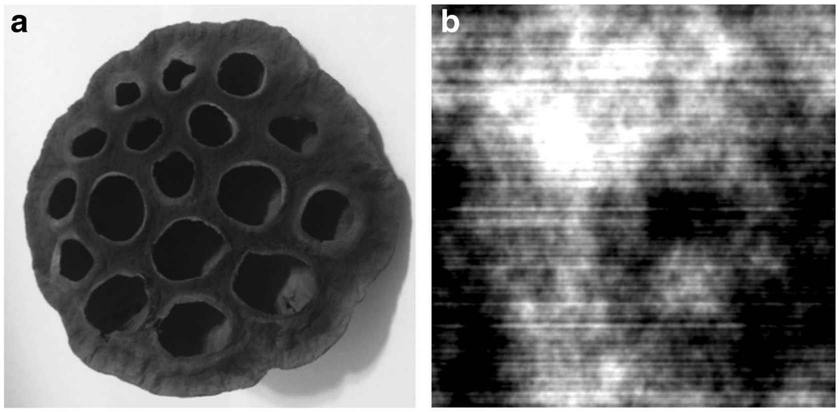

Fig. 1 Image of a lotus seed head as an example of a trypophobic image (**a**). A phase-scrambled version of the image (**b**)

1989). The affect grid measures a single item along two affect dimensions: pleasant–unpleasant and arousal–sleepiness. The participants were asked to evaluate the images that were presented in the preceding saccade task (Experiment 1: trypophobic, fearful, neutral, and filler images; Experiment 2: PS-T, PS-F, PS-N, and phase-scrambled filler images). For each trial, an image (11° × 11°) appeared at the center of the display for 5,000 ms, followed by an affect grid. The participants had to evaluate the valence and arousal of the images by mouse clicking one of the cells of the grid. The horizontal axis of the grid indicated valence (from 1 = *pleasant* to 9 = *unpleasant*), and the vertical axis indicated arousal (from 1 = *sleepy* to 9 = highly *aroused*). The participants completed 192 trials. The experiment was controlled by a program written in PsychoPy (Peirce, 2007).

Data analysis

Saccade task Eye movements were recorded and the criteria for saccades defined as follows. Eye movement latency was defined as the interval between arrow onset and initiation of an eye movement. When the latency was shorter than 80 ms or longer than 600 ms, the eye movement was not defined as a saccade, and the trial was removed from the analysis. Furthermore, if no eye movement or only small eye movements (<3°) were observed, no saccade was detected, and these trials were also omitted from further analysis. We analyzed the trials in which the distractor was presented in the same hemifield as the direction of the saccades.

The influence of distractor images on saccades was analyzed using two metrics, saccade curvature and saccade endpoint deviation (see Fig. 4). We calculated coordinate points of the saccade paths for each 1-ms sample point that was between 1.5° from the central fixation and 1.5° from the endpoint of the saccade. We then calculated the saccade curvature as an angle between two straight lines: one connecting the starting point and endpoint and the other connecting the starting point and the maximum curvature point that deviated most from a straight line from the starting point to the endpoint. We calculated saccade endpoint deviation relative to a straight line from the starting point to the target. Positive values indicate that a saccade was directed away from the distractor location. Negative values indicate that a saccade was directed towards the distractor location. Saccade curvature and endpoint deviation together comprised a 3 (distractor type: trypophobic, fearful, and neutral) × 3 (SOA: 0 ms, 150 ms, and 450 ms) experimental design.

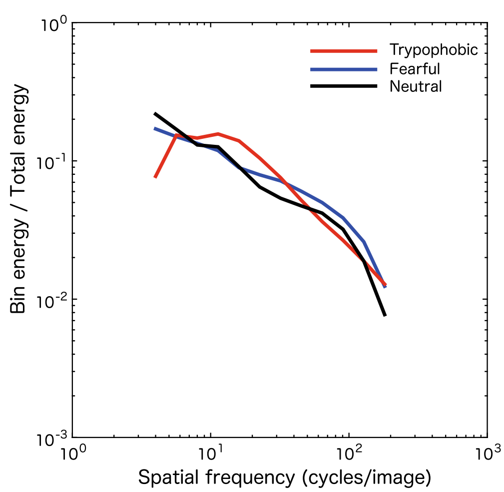

Fig. 2 Power spectral characteristics of each image type. Abscissae: spatial frequencies. Ordinates: power spectrum of each band of the spatial frequencies (bin energy) / power spectrum averaged over all bands of spatial frequencies (total energy)

Evaluation task We used valence and arousal ratings from the evaluation task to investigate whether such differences affected the eye movements. For example, when the coordinates (*x*, *y*) of the clicked location were (1, 9), this meant that the level of valence was 1 and the level of arousal was 9. Mean valence and arousal scores were calculated for each image type. The evaluation task data in Experiment 2 were collected from 18 undergraduate students; two students (one male and one female) did not participate in this task.

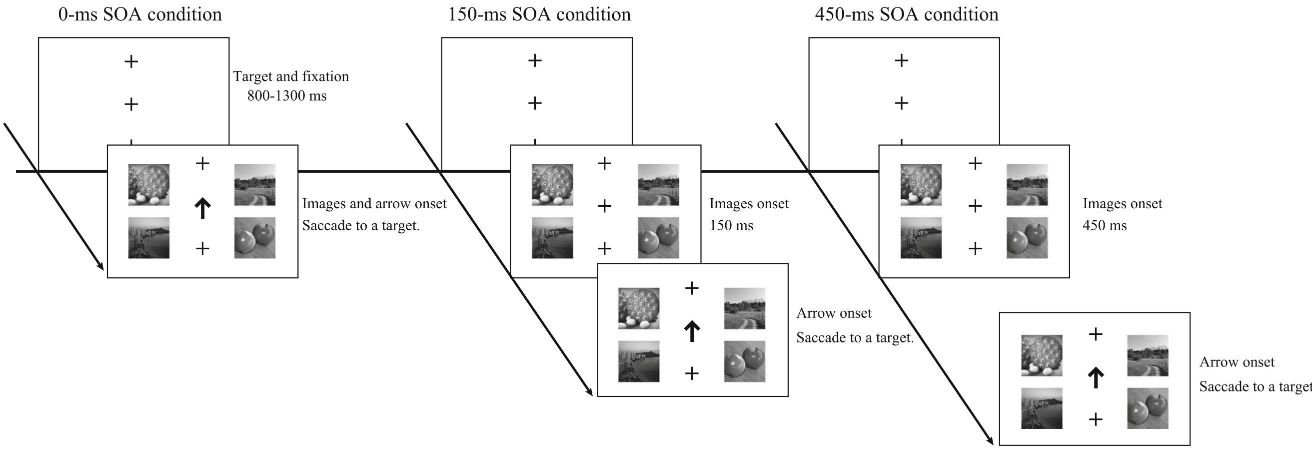

Fig. 3 Procedure of eye-movement experiment

Experiment 1

In Experiment 1, we examined whether the trypophobic images capture attention automatically and whether they affect eye-movement programming.

Results

Eye-movement task Some experimental trials were excluded from the analyses based on the criteria described before (17.38% in the trypophobic condition, 18.33% of the trials in the fearful condition, and 17.89% in the neutral condition). Figure 5 shows saccade trajectories for each distractor image and SOA condition in Experiment 1. Saccade trajectories appear to deviate toward the trypophobic images in the same hemifield condition at the 0-ms SOA condition.

The effects on saccade curvature are illustrated in Fig. 6a. Saccade curvatures were subjected to a two-way ANOVA

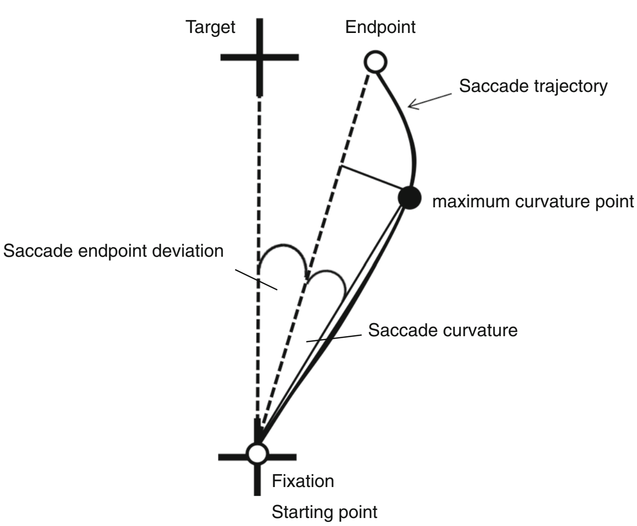

Fig. 4 Calculation of two metrics from saccade trajectories: saccade endpoint deviation and saccade curvature

with factors of distractor image (trypophobic, fearful, or neutral) and SOA condition (0, 150, or 450 ms). The main effect of image, $F(2, 34) = 0.52$, $p = .60$, $\eta_p^2 = .03$, main effect of SOA, $F(2, 34) = 0.36$, $p = .56$, $\eta_p^2 = .02$, and the interaction between image and SOA, $F(4, 68) = 0.24$, $p = .91$, $\eta_p^2 = .01$, were all nonsignificant. Saccade curvatures thus did not differ across distractor image type.

The saccade endpoints showed greater deviation toward the trypophobic images compared with the other images (see Fig. 6b). The degree of endpoint deviation was subjected to a two-way ANOVA with factors of distractor image (trypophobic, fearful, or neutral) and SOA condition (0, 150, or 450 ms). The main effect of image was significant, $F(2, 34) = 5.92$, $p < .01$, $\eta_p^2 = .26$. Multiple comparisons using the Holm method showed that the endpoint deviations toward trypophobic images (−0.19°) were larger than those toward neutral images (0.04°), $t(17) = 2.80$, $p = .04$, $d = 0.65$. Moreover, the saccade endpoint tended to deviate more toward trypophobic images (−0.19°) than fearful images (−0.06°), but this difference did not reach statistical significance, $t(17) = 2.27$, $p = .07$, $d = 0.38$. There was no significant difference in saccade endpoint deviations between fearful and neutral images, $t(17) = 1.65$, $p = .12$, $d = 0.33$. However, there was a significant main effect of SOA, $F(2, 34) = 5.90$, $p < .01$, $\eta_p^2 = .26$. Multiple comparisons showed that the saccade endpoint deviations were larger for the 0-ms SOA condition (−0.17°) than the 150-ms SOA (−0.04°), $t(17) = 2.93$, $p = .02$, $d = 0.41$, and 450-ms SOA conditions (−0.003°), $t(17) = 3.18$, $p = .02$, $d = 0.50$. The interaction between image and SOA was not observed, $F(4, 68) = 0.91$, $p = .47$, $\eta_p^2 = .05$, indicating that the trypophobic images caused larger endpoint deviations compared with the neutral images regardless of SOA conditions. However, as seen in Fig. 5, the saccade trajectories deviated toward trypophobic images, particularly in the 0-ms SOA condition. To confirm whether each distractor image induced the saccade endpoint deviations at each SOA condition, we conducted one-sample t tests of the differences

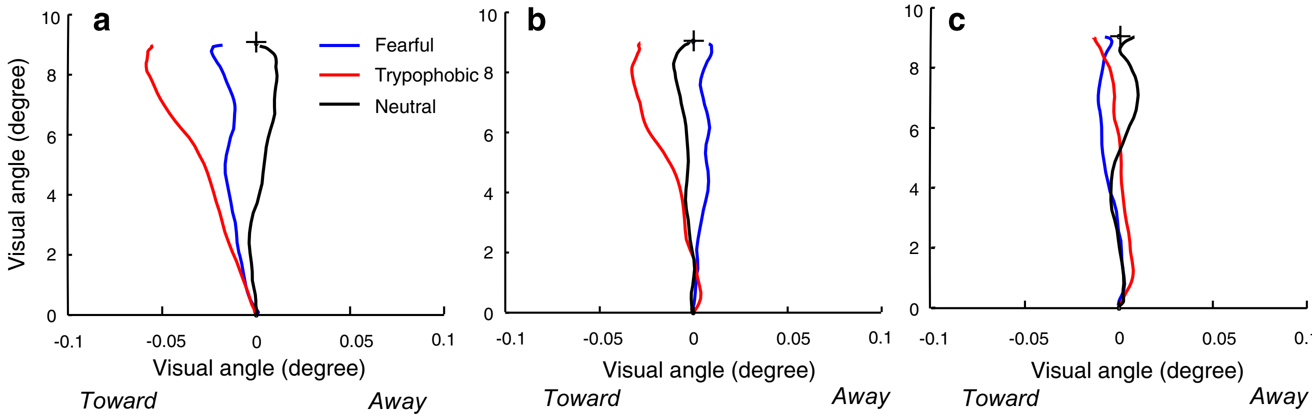

Fig. 5 Mean saccade trajectories across participants for each type of distractor image and SOA condition in Experiment 1. 0-ms SOA condition (**a**), 150-ms SOA condition (**b**), and 450-ms SOA condition (**c**). Positive values indicate saccades directed away from the distractor, whereas negative values indicate saccades directed toward the distractor

between the saccade endpoint deviations toward each distractor image (trypophobic, fearful, or neutral) at each SOA condition (0, 150, or 450 ms) and a hypothetical mean of zero (similar to the method used by Schmidt et al., 2012). Consistent with this observation, the one-sample t tests revealed that the saccade endpoint deviations toward trypophobic images in the 0-ms SOA condition (−0.38°) were significantly different from zero, $t(17) = 3.65, p < .01, d = 1.25$. Furthermore, the saccade endpoint deviations were not different from zero in the other conditions, $ts(17) < 1.79$. Thus, the trypophobic images seem to exert their greatest effects at the early stages of saccade programming. The overall results suggest that saccades did deviate toward the trypophobic images.

Previous studies showed that the saccades deviated toward the distractor when the saccade latency was short, because distractor-related inhibitory processing is relatively slow (McSorley, Cruickshank, & Inman, 2009; McSorley, Haggard, & Walker, 2006). Supposing that the trypophobic images hasten the saccade onset for any reason, it is plausible that the larger saccade endpoint deviation toward trypophobic images was caused merely by a shorter latency. We examined this possibility (see Fig. 7). Saccade latency was subjected to a two-way ANOVA with distractor image (trypophobic, fearful, or neutral) and SOA conditions (0 ms, 150 ms, or 450 ms). The main effect of distractor image was significant, $F(2, 34) = 10.86, p < .001, \eta_p^2 = .39$. Multiple comparisons revealed that saccade latency was significantly shorter for neutral images (231.32 ms) compared to trypophobic (232.88 ms), $t(17) = 2.93$, $p < .05$, $d = 0.04$, and fearful images (233.37 ms), $t(17) = 4.23$, $p < .001$, $d = 0.05$. There was no significant difference in saccade latency between fearful and trypophobic images, $t(17) = 1.46, p = .16, d = 0.01$. These results suggested that the fearful images captured attention to a similar degree. However, because saccade latency was similar for trypophobic and fearful images, the specific effect of trypophobic images on saccade endpoint deviation likely does not depend on saccadic latencies. In addition, there was a significant effect of SOA, $F(2, 34) = 62.41$, $p < .001$, $\eta_p^2 = .80$. The latency in the 0-ms SOA condition (248.52 ms) was significantly longer than in both the 150-ms (227.53 ms), $t(17) = 7.99$, $p < .001$, $d = 0.48$, and 450-ms SOA conditions (221.52 ms), $t(17) = 8.27$, $p < .001$, $d = 0.64$. Moreover, the

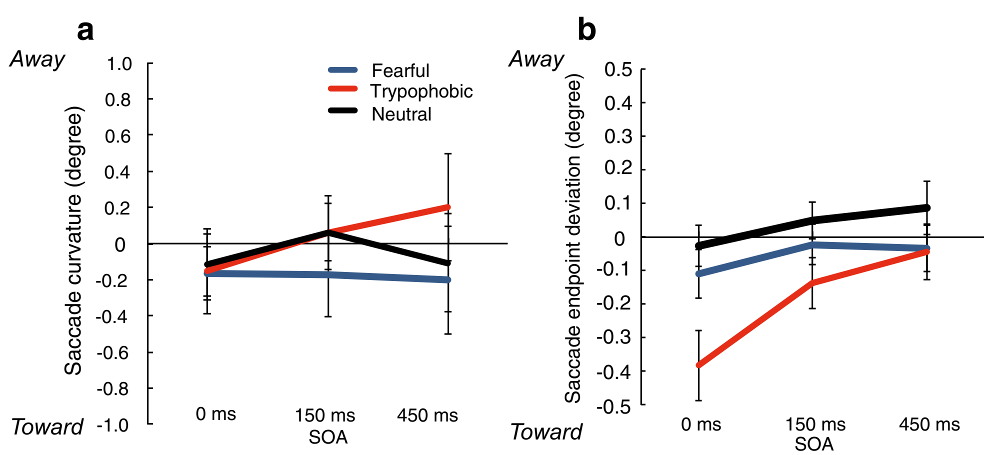

Fig. 6 Saccade curvature (**a**) and saccade endpoint deviation (**b**) in Experiment 1. Error bars reflect standard error of the mean

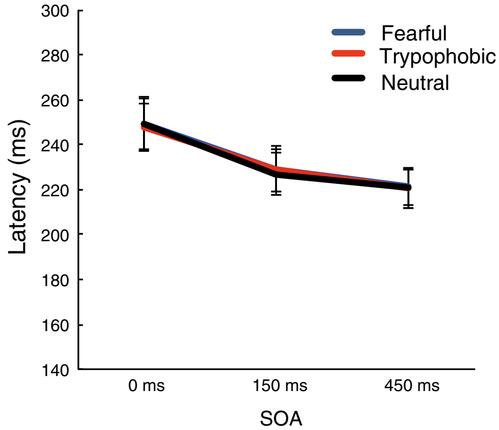

Fig. 7 Saccade latencies in Experiment 1. Error bars reflect standard error of the mean

150-ms SOA yielded longer latencies than the 450-ms SOA condition (221.52 ms), $t(17) = 4.54$, $p < .001$, $d = 0.16$. The interaction between image and SOA was not significant, $F(4, 68) = 1.39$, $p = .25$, $\eta_p^2 = .08$. These results indicate that the saccade latencies were longer when the SOAs were shorter, regardless of the image type.

Evaluation task Figure 8a shows mean valence scores for each image type, which were larger for fearful and trypophobic images than for neutral and filler images. A one-way within-subjects ANOVA on valence scores (trypophobic, fearful, neutral, and filler) revealed significant differences between image types, $F(3, 51) = 90.32$, $p < .001$, $\eta_p^2 = .84$. The main effect of image type was examined with a paired-sample t test using the Holm method, which showed that the valence scores of fearful images ($M = 7.08$) were significantly larger than those of neutral ($M = 4.16$), $t(17) = 9.26$, $p < .001$, $d = 2.98$, and filler images ($M = 4.21$), $t(17) = 9.57$, $p < .001$, $d = 2.99$. Moreover, valence scores of trypophobic images ($M = 7.57$) were significantly larger than those of neutral, $t(17) = 11.54$, $p < .001$, $d = 3.51$, and filler images, $t(17) = 12.39$, $p < .001$, $d = 3.53$. However, valence scores did not differ between fearful and trypophobic images, $t(17) = 1.66$, $p = .23$, $d = 0.50$, or between neutral and filler images, $t(17) = 0.77$, $p = .45$, $d = 0.05$. Since the valence scores did not differ between fearful and trypophobic images in the evaluation task, it is plausible that the saccade endpoint deviations toward the trypophobic images were not due to image valence.

Figure 8b shows mean arousal scores for each image. Arousal from fearful and trypophobic images was greater than from neutral and filler images. A one-way within-subjects ANOVA on arousal scores (trypophobic, fearful, neutral, and filler) revealed significant differences between image types, $F(3, 51) = 44.77$, $p < .001$, $\eta_p^2 = .73$. Arousal scores of fearful images ($M = 6.78$) were significantly larger than those of neutral ($M = 3.84$), $t(17) = 7.16$, $p < .001$, $d = 2.22$, and filler images ($M = 3.67$), $t(17) = 8.24$, $p < .001$, $d = 2.48$. Moreover, arousal scores of trypophobic images ($M = 6.10$) were significantly larger than scores for neutral, $t(17) = 6.89$, $p < .001$, $d = 1.61$, and filler images, $t(17) = 7.71$, $p < .001$, $d = 1.81$. However, arousal scores did not differ between fearful and trypophobic images, $t(17) = 1.83$, $p = .17$, $d = 0.50$, nor between neutral and filler images, $t(17) = 1.55$, $p = .17$, $d = 0.13$. The effect of trypophobic images on saccade endpoint deviations does not appear to depend on differences in the arousal strengths between fearful and trypophobic images.

Discussion

The endpoint of saccades deviated toward trypophobic images, but not toward fearful or neutral images, suggesting that the trypophobic images strongly captured attention and might modulate the activation of the oculomotor system. Moreover, as the evaluation scores (valence and arousal) did not differ significantly between fearful and trypophobic images, the saccade endpoint deviation toward trypophobic images was likely not due to differences in explicit evaluation of the images.

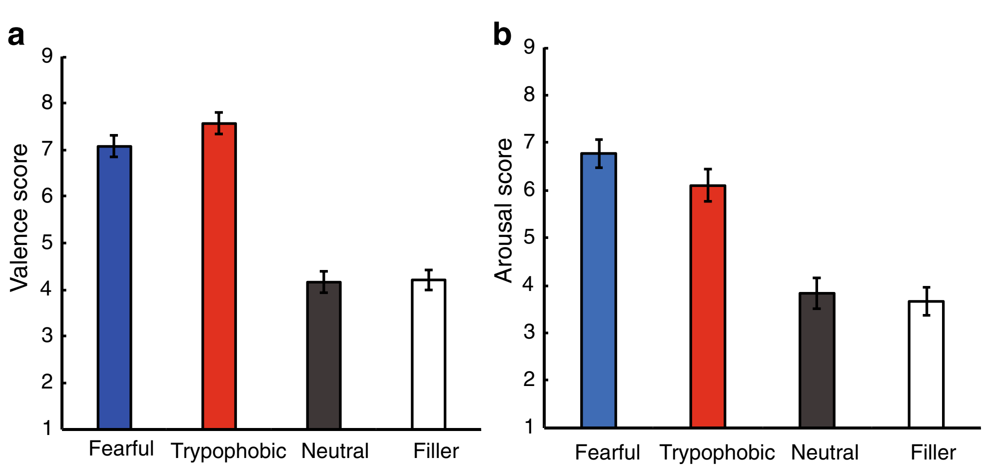

Fig. 8 Results of evaluation task showing valence scores (**a**) and arousal scores (**b**) in Experiment 1. Error bars reflect standard error of the mean

These results suggest that the trypophobic power spectra might affect oculomotor programming without the mediating influence of explicit evaluation.

Experiment 2

In Experiment 2, we further examined the role of spectral characteristics of trypophobic images in eye-movement programming. The procedure was identical to that of Experiment 1, with the exception that distractor and filler images were converted to phase-scrambled images. If phase information does not contribute to attentional capture, phase-scrambled trypophobic images would affect the saccade trajectories in similar ways as observed in Experiment 1. However, if the phase information does contribute to attentional capture, not all phase-scrambled images would affect the saccade trajectories.

Results

Eye-movement task The following proportions of trials were excluded from analyses based on the various criteria: 13.81% of the trials in the PS-T condition, 14.01% of the trials in the PS-F condition, and 14.47% of the trials in the PS-N condition.

Figure 9 shows saccade trajectories for each distractor image type and SOA condition. Figure 1a shows the saccade curvature. Saccade curvatures were subjected to a two-way within-subjects ANOVA with factors of image (trypophobic, fearful, or neutral) and SOA condition (0, 150, or 450 ms). We found a significant main effect of image, $F(2, 38) = 8.51$, $p < .001$, $\eta_p^2 = .31$, but no main effect of SOA, $F(2, 38) = 0.54$, $p = .59$, $\eta_p^2 = .03$, or interaction between image and SOA, $F(4, 76) = 0.89$, $p = .47$, $\eta_p^2 = .04$. Multiple comparisons using the Holm method showed that the saccade curvature away from PS-T images (0.31°) was larger than for PS-N images (−0.25°), $t(19) = 4.15$, $p < .01$, $d = 0.73$, though there were no differences between PS-F images and PS-N images, $t(19) = 2.18$, $p = .08$, $d = 0.32$, or between PS-F images and PS-T images, $t(19) = 1.98$, $p = .08$, $d = 0.34$. To further assess the effect of image type on saccade trajectories, one-sample *t* tests between the various image types and zero were conducted. The curvature away from PS-T images (0.43°) was significantly larger than zero for the 0-ms SOA condition, $t(19) = 2.55$, $p < .05$, $d = 0.83$. Saccade curvature for PS-N images was −0.34° at the 0-ms SOA condition, and this curvature was significantly smaller than zero, $t(19) = 2.12$, $p < .05$, $d = 0.69$. The saccade curvatures for the other conditions were not different from zero, $ts(19) < 1.72$). The *t*-test analyses showed that saccades curved away from PS-T images compared with PS-F and PS-N images. The overall saccade curvature findings suggest that PS-T images captured attention and induced inhibition of the distractor location in order to correctly saccade toward the target.

Figure 10b shows the saccade endpoint deviation. Saccade endpoint deviations were subjected to a two-way ANOVA with the phase-scrambled distractor image (trypophobic, fearful, or neutral) and SOA condition (0 ms, 150 ms, or 450 ms) as within-subjects factors. The analyses of saccade endpoint deviations yielded no statistically significant effects for image, $F(2, 38) = 1.30$, $p = .28$, $\eta_p^2 = .06$, SOA, $F(2, 38) = 0.19$, $p = .83$, $\eta_p^2 = .01$, and no interaction between image and SOA, $F(4, 76) = 1.98$, $p = .11$, $\eta_p^2 = .09$. These results suggest that although the PS-T images might capture attention, attention was suppressed successfully.

Saccade latency results are illustrated in Fig. 11. Saccade latency was subjected to a three-way ANOVA with distractor image (PS-T, PS-F, or PS-N images) and SOA condition (0 ms, 150 ms, or 450 ms) as within-subjects factors. Saccade latencies were significantly affected by SOA, $F(2, 38) = 96.12$, $p < .001$, $\eta_p^2 = .84$, but not by distractor image, $F(2,$

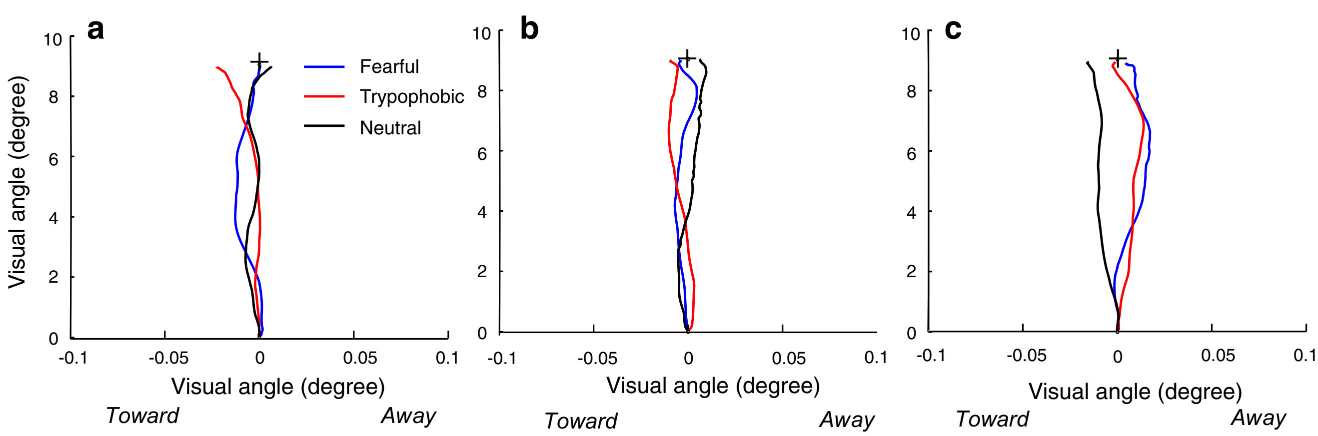

Fig. 9 Mean saccade trajectories across participants for each distractor image type and SOA condition in Experiment 2. 0-ms SOA condition (**a**), 150-ms SOA condition (**b**), and 450-ms SOA condition (**c**). Positive values indicate saccades directed away from the distractor, whereas negative values indicate saccades directed toward the distractor

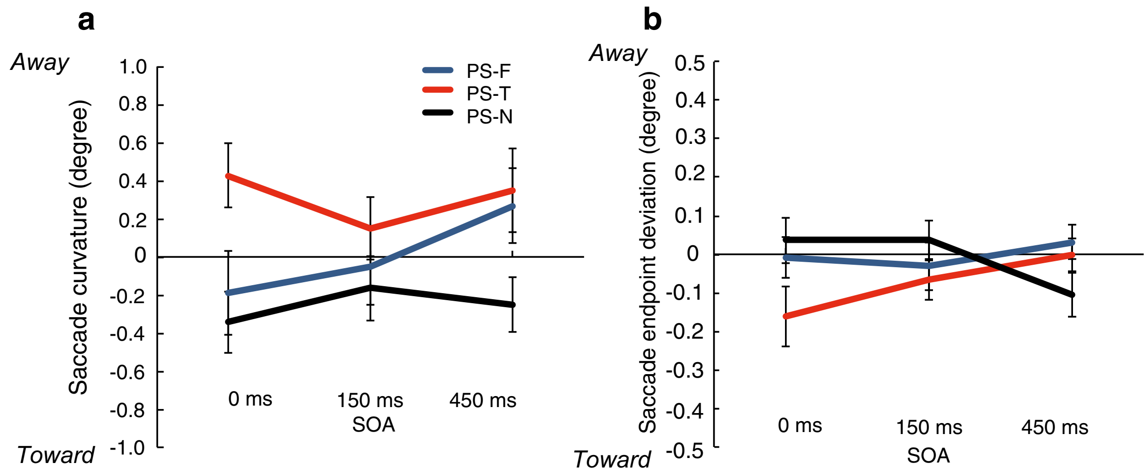

Fig. 10 Saccade curvature (**a**) and saccade endpoint deviation (**b**) in Experiment 2. Error bars reflect standard error of the mean

38) = 1.48, $p = .24$, $\eta_p^2 = .07$. Multiple comparisons using the Holm method showed that the 0-ms SOA condition (258.56 ms) yielded significantly longer latencies than both the 150-ms (229.46 ms), $t(19) = 10.83$, $p < .001$, $d = 0.86$, and 450-ms SOA conditions (223.20 ms), $t(19) = 9.79$, $p < .001$, $d = 1.05$. Moreover, the 150-ms SOA condition yielded longer latencies than the 450-ms SOA condition, $t(19) = 4.48$, $p < .001$, $d = 0.22$. However, the interaction between image and SOA was not significant, $F(4, 76) = 1.49$, $p = .21$, $\eta_p^2 = .07$, suggesting that the three image types affected saccade latencies similarly across the different SOA variations.

Evaluation task The mean valence scores for PS-F and PS-T images were higher than those for neutral and filler images (see Fig. 12a). A one-way within-subjects ANOVA on valence scores (PS-T, PS-F, PS-N, and filler) revealed significant differences between the images, $F(3, 51) = 30.14$, $p < .001$, $\eta_p^2 = .64$. Specifically, valence scores for PS-T images ($M = 6.34$) were significantly higher than scores for the other types of images; PS-F images ($M = 5.51$), $t(17) = 5.79$, $p < .001$, $d = 0.88$; PS-N images ($M = 5.03$), $t(17) = 5.23$, $p < .001$, $d = 1.40$; and filler images ($M = 4.95$), $t(17) = 6.95$, $p < .001$, $d = 1.56$. Furthermore, valence scores for PS-F images were larger than those for PS-N, $t(17) = 3.37$, $p < .01$, $d = 0.61$, and filler images, $t(17) = 5.09$, $p < .001$, $d = 0.75$. Importantly, PS-F images had lower valence scores compared with PS-T images. These results show that the characteristic trypophobic spectrum caused discomfort.

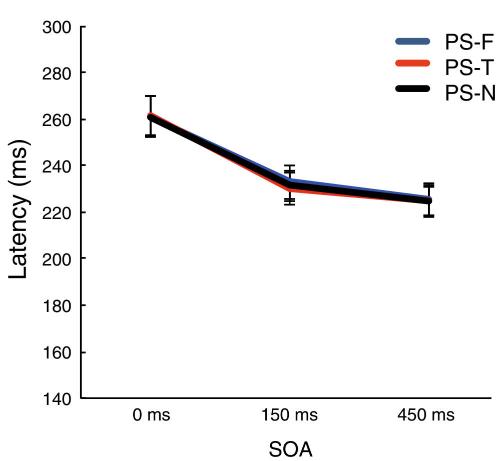

Fig. 11 Saccade latencies in Experiment 2. Error bars reflect standard error of the mean

Figure 12b shows mean arousal scores for each image type. PS-F and PS-T images elicited more arousal than PS-N and filler images. A one-way within-subjects ANOVA conducted on arousal scores (PS-T, PS-F, PS-N, and filler) revealed significant differences between image types, $F(3, 51) = 17.81$, $p < .001$, $\eta_p^2 = .51$. Specifically, arousal from PS-T images ($M = 4.92$) was significantly greater than from other types of images; PS-F images ($M = 4.09$), $t(17) = 4.94$, $p < .001$, $d = 0.72$, PS-N images ($M = 3.93$), $t(17) = 4.41$, $p < .01$, $d = 0.84$, and filler images ($M = 3.91$), $t(17) = 5.12$, $p < .001$, $d = 0.87$. The characteristic trypophobic spectrum might have caused high arousal with negative emotional experience, in agreement with Cole and Wilkins (2013).

Discussion

The results of Experiment 2 demonstrated that saccades curved away from the phase-scrambled trypophobic images. We argue that the trypophobic spectral features bias the saccade trajectories. Theories of visual perception have suggested that the first stage of visual analysis includes the processing of spatial frequencies (e.g., Hegde, 2008; Kauffmann, Ramanoël, & Peyrin, 2014). Moreover, several studies have

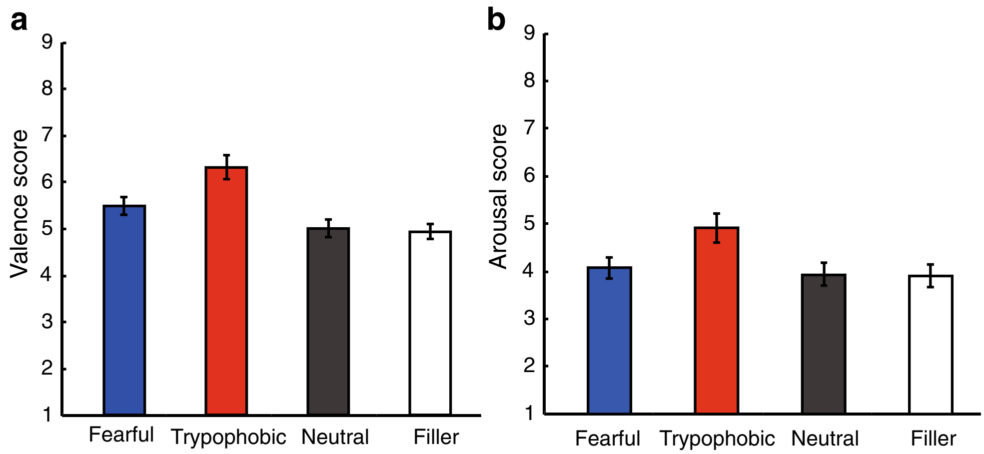

Fig. 12 Results of evaluation task showing valence scores (**a**) and arousal scores (**b**) in Experiment 2. Error bars reflect standard error of the mean

suggested that spatial frequencies play an important role in an effective detection-avoidance strategy (e.g., Bannerman, Hibbard, Chalmers, & Sahraie, 2012; Gao, LoBue, Irving, & Harvey, 2017). We showed that even when the phase information was scrambled, the trypophobic images elicited more discomfort than the fearful and neutral images. This result is in line with the claim of Cole and Wilkins (2013), who argued that the trypophobic images induce discomfort because they have excess power energy at midranges of spatial frequencies. Indeed, previous studies have suggested that discomfort induced via repetitive visual patterns can reduce performance on a visual search task (e.g., Conlon, Lovegrove, Hine, Chekaluk, Piatek, & Hayes-Williams, 1998). Thus, it is likely that the discomfort elicited by the trypophobic patterns modulates visual processing, which is reflected in the present finding that saccades curved away from the phase-scrambled trypophobic images.

The trypophobic spectra themselves might affect the early stage of saccade programming. Indeed, we observed saccade curvature away from the phase-scrambled trypophobic images particularly at a 0-ms SOA. This curvature effect was not obvious in longer SOA conditions. This pattern is in line with Godijn and Theeuwes (2004), who demonstrated that the saccade curvature induced by a distractor became smaller as the SOA between the distractor and a saccade target became longer. We suggest that when there is enough time to prepare a saccade (i.e., the long SOA condition), the programming of saccades is fully controlled, such that the saccade can go straight to the correct target position.

General discussion

The aim of the present study was to examine whether and how trypophobic images affect visual attentional processing by measuring saccadic eye movements. The participants made a saccade to a target indicated by an arrow cue while four irrelevant images appeared at the periphery. In Experiment 1, one of the irrelevant images was a trypophobic, fearful, or neutral image. We found that the endpoints of saccades directed toward the intact trypophobic images, and that the deviation decreased as the SOA between trypophobic image onset and the onset of a saccade became longer. The same procedure as in Experiment 1 was carried out in Experiment 2, with the exception that all images were phase-scrambled. We found that the trypophobic images still affected saccade trajectories even when their phase information was scrambled. However, contrary to Experiment 1, saccades curved away from the phase-scrambled trypophobic images in Experiment 2, which is a similar pattern of saccade trajectory as that seen for angry face distractors (Schmidt et al., 2012).

Although the Experiment 1 results seem to contrast with those of Experiment 2, we think that the overall pattern can be explained by a single mechanism. It has been suggested that the saccade curvatures reflect attentional capture by the distractor and subsequent inhibition at the distractor location (e.g., Van der Stigchel et al., 2006). When the distractor has salient features, it should evoke a large degree of inhibition and therefore induce saccade curvatures from the location of the distractor. However, if the distractor captures attention too strongly to be sufficiently suppressed, the direction of the saccades would be biased toward the distractor, with the saccade endpoint landing closer to the distractor location. On the basis of this assumption, we speculate that the intact trypophobic images might capture attention very strongly, and therefore that the endpoints of saccades might deviate toward the trypophobic images. On the other hand, attentional capture by the phase-scrambled trypophobic images might be sufficiently suppressed, resulting in the saccade curvature away from such images. Taken together, our experiments demonstrated that the intact and phase-scrambled trypophobic images caused different degrees of inhibition for the distractor locations, leading to differential modification of the saccade trajectories.

Why did trypophobic images affect saccade trajectories more strongly when the phase structures of the image were preserved? Since the phase spectra determine image structures such as edges and curves (e.g., Banno & Saiki, 2015; Kovesi, 2000, 2003), phase information is critical for understanding the gist of an image. The visual system can extract the gist of a natural scene very rapidly (Thorpe, Fize, & Marlot, 1996; Thorpe, Gegenfurtner, Fabre-Thorpe, & Bülthoff, 2001) even at the periphery and in the near absence of attention (Li, VanRullen, Koch, & Perona, 2002). The gist of trypophobic images may be extracted very rapidly and then affect the early stages of the attentional system additively with the effect of the specific power spectrum of the image, resulting in saccade trajectory deviation even in shorter SOA conditions.

Although previous studies reported saccade curvature away from fearful images (Nummenmaa et al., 2009; Petrova & Wentura, 2012; Schmidt et al., 2012), our experiments showed neither saccade curvature nor endpoint deviation for the fear distractors. This might be due to the content of images that were presented. The previous studies used fearful images including human bodies or faces (Nummenmaa et al., 2009; Petrova & Wentura, 2012; Schmidt et al., 2012), whereas we used images that contained fear-related animals. Although there is ample evidence for fear-related attentional bias elicited by animal images, some studies have reported no attentional bias for fearful animal stimuli (e.g., Tipples, Young, Quinlan, Broks, & Ellis, 2002; Lipp, Derakshan, Waters, & Logies, 2004; Miltner, Krieschel, Hecht, Trippe, & Weiss, 2004). For example, Tipples et al. (2002) showed that when participants searched for a specific type of the target (e.g., animals) among non-target pictures (e.g., plants), the threatening (e.g., snakes and spiders) and non-threatening animals (e.g., cats and horses) were detected comparably quickly. They suggested that the lack of attentional bias to the threatening animals might be due to their samples consisting mainly of low anxiety participants. Indeed, Öhman et al. (1999) reported that rapid detection of snakes and spiders was observed in participants with a high fear of such animals (see also Devue et al., 2011). Thus, attentional bias to the threatening stimuli may be only observed in highly anxious individuals. Because the present study did not measure traits (e.g., trait anxiety), we cannot determine whether such traits modulated the saccade curvature effect. Here, we argued the possibility that the sensitivity of the individuals to the specific visual stimuli might modulate attentional bias for these stimuli. If so, the individuals with high proneness to trypophobia may show stronger attentional biases toward the trypophobic images. Future research should examine to what extent individual difference variables related to fear or anxiety influence the modification of the saccade trajectories by emotional stimuli.

In summary, the present study demonstrated that the trypophobic power spectra affected attentional processing in an automatic or "bottom-up" fashion. Moreover, it seems that not only the trypophobic power spectra but also the gist of a trypophobic image modulate the oculomotor system. Our findings suggest that the unique spectral features in a complex visual scene not only cause discomfort, but also affect automatically affect the oculomotor system.

Author note Risako Shirai, Department of Integrated Psychological Sciences, Kwansei Gakuin University, Japan; Hayaki Banno, Department of Health Promotion Science, Tokyo Metropolitan University, Japan; Hirokazu Ogawa, Department of Integrated Psychological Sciences, Kwansei Gakuin University, Japan.

Appendix 1

Table 1 IAPS numbers of used images

5250	5260	5551	5593	5594	5600	5611	5660	5661	5700	5711
5720	5740	5750	5760	5764	5780	5781	5800	5811	5814	5820
5833	5870	5982	5990	5991	5994	7004	7006	1460	1463	1610
1710	1750	1920	2040	2070	2071	7325	1030	1040	1050	1051
1052	1070	1080	1090	1101	1110	1113	1114	1120	1200	1201
1205	1220	1230	1240	7009	7010	7020	7025	7035	7039	7041
7050	7052	7053	7057	7100	7130	7140	7150	7170	7175	7180
7186	7190	7205	7211	7224	7223	7235	7508	7545	8190	8191
1300	1302	1303	1930	1931	1932	1022	1026			

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