Threat modulates perception of looming visual stimuli

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Among the most critical of visual functions is the detection of potentially hazardous or threatening aspects of the environment. For example, objects on a collision course with an observer must be quickly identified to allow sufficient time to prepare appropriate defensive or avoidant responses. Directly approaching objects produce a specific accelerating pattern of optical expansion, known as ‘looming’, which in theory exactly specifies time-to-collision independent of object size or distance. Such looming stimuli have been shown to trigger stereotyped defensive responses in both monkeys [1] and human infants [2]. Psychophysical results in adult participants have similarly suggested sensitivity to looming at early stages of visual processing [3]. Such findings indicate specialization of the visual system to detect and react to such ‘looming’ stimuli, and have contributed to the traditional view of looming as a purely optical cue to imminent collision [1]. Here, we investigated whether the semantic content of a looming visual stimulus affects perceived time-to-collision by manipulating its threat value. We show that time-to-collision is underestimated for threatening (snakes and spiders) compared to non-threatening (butterflies and rabbits) stimuli. Further, the magnitude of this effect relates with self-reported fear. Our results demonstrate affective modulation of the perception of looming stimuli, and suggest that emotion shapes basic aspects of visual perception.

Participants made time-to-collision judgments of looming visual stimuli that expanded in size over one second before disappearing (see Supplemental Experimental Procedures for details). The rate of image expansion was consistent with one of five time-to-collisions between three and five seconds. Stimuli were photographs of animals, commonly perceived as threatening (snakes and spiders) or non-threatening (butterflies and rabbits). Participants were instructed to imagine each stimulus continuing to approach after it disappeared and to judge when it would have collided with them by pressing a button with their right hand at that exact moment.

Judged time-to-collision increased monotonically with actual time-to-collision (Figure 1, left panel), though the rate of this increase was substantially less than would be predicted of an ideal observer, consistent with previous findings [4]. Critically, threatening stimuli were judged as colliding sooner than non-threatening stimuli. Though the pattern of optical expansion was exactly constant across conditions, the content of the looming stimuli nevertheless modulated perceived time-to-collision. Our data are consistent with previous results showing that humans are sensitive to looming as a cue to collision [4], but, critically, that these judgments are also affected by the semantic content of approaching stimuli.

We further investigated whether the magnitude of this effect relates to individual differences in fear of snakes and spiders. We used a self-report questionnaire commonly used for clinical assessment of spider phobia (see Supplemental Experimental Procedures), and adapted the items by substituting each category name for the word ‘spider’. To isolate individual differences in fear, we regressed fear ratings for threatening stimuli on ratings for non-threatening stimuli, and calculated the residuals. Similarly, we regressed time-to-collision judgments for threatening on those for non-threatening stimuli, and calculated the residuals. These residuals were negatively correlated (Figure 1, right panel), indicating that fear of snakes and spiders was associated with larger underestimation of time-to-collision of these stimuli.

Experiment 2 controlled for potential low-level confounds in the images by comparing time-to-collision judgments for the images used in Experiment 1 with scrambled versions of these images. Time-to-collision judgments were again reduced for threatening compared to non-threatening stimuli. Critically, this effect disappeared for the scrambled

Figure 1. Experimental results.
Left panel: judged time-to-collision increased monotonically as a function of actual time-to-collision for non-threatening (butterflies and rabbits) and threatening (snakes and spiders) stimuli, \( F(4, 112) = 47.09, p < 0.0001 \). The light grey dotted line indicates veridical judgments. There was a clear bias to underestimate time-to-collision for threatening compared to non-threatening stimuli, \( F(1, 29) = 12.35, p < 0.005 \). Right panel: scatterplot showing relation of time-to-collision judgments and fear. For both time-to-collision judgments and fear ratings, variance specifically related to the threatening stimuli was isolated by calculating the residuals, regressing scores for threatening on those for non-threatening stimuli. These residuals were significantly negatively correlated, \( r(29) = -0.367, p < 0.05 \), indicating that greater fear was associated with increased underestimation of time-to-collision.
images, demonstrating that the effect is not driven by incidental stimulus-related characteristics. Further, threatening — but not non-threatening — stimuli were judged as arriving earlier than scrambled versions of the same images, suggesting that the effect is driven specifically by responses to threatening stimuli.

Experiment 3 investigated whether reduced time-to-collision judgments could reflect a non-specific effect of seeing threatening stimuli, such as heightened arousal. Participants saw threatening or non-threatening stimuli for one second, immediately followed by a looming blue disc. If the effect we report is a non-specific effect of seeing threatening stimuli, time-to-collision judgments of the blue disc should be faster when preceded by images of threatening stimuli. Contrary to this prediction, priming images had no apparent effect on time-to-collision judgments of a semantically-neutral disc.

Threatening stimuli are perceived as approaching more rapidly than non-threatening stimuli, especially for those who are fearful of those objects. These results show, in contrast to the traditional view of looming as a purely optical cue to object approach [1], that perceiving the time of imminent collision is not entirely driven by purely optical cues, but is also subject to emotional modulation. Gibson and colleagues [1] pointed out that as an optical cue to imminent collision, visual looming is a direct perceptual indicator of threat. Our results suggest that the affective content of looming stimuli also affects perceived time-to-collision. Underestimating arrival time of threatening stimuli may thus serve an adaptive role in leading responses to err on the side of additional time for either flight or flight. Some perceptual biases appear only for explicit perceptual judgments, but not for visually-guided actions [5]. Thus, it is possible that the present effect reflects a purely perceptual distortion that might not affect actions, such as catching.

Recent findings have demonstrated that emotion modulates some basic aspects of perception, such as visual contrast sensitivity [6], but not others, such as auditory directional attention [7]. The selectivity of emotional effects on perception is consistent with anecdotal reports that specific phobias may induce category-specific distortions of perception [8]. Though we investigated variability in fear in an unselected sample (i.e. generally non-phobic), our results provide experimental evidence consistent with this proposal. Other recent results have also suggested that individual differences in fear, even in the non-clinical range, alter space perception. For example, fear of heights is associated with distorted perception of vertical distance [9], whereas claustrophobic fear is associated with increased size of the near space immediately surrounding the body [10]. The present results fit with and extend these by showing that emotion not only alters the perception of space as a static entity, but it also affects the perception of dynamically moving objects, such as those on a collision course with the observer.

Supplemental Information
Supplemental Information includes experimental procedures and two figures and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2012.07.053.

References

Groups have a larger cognitive capacity than individuals

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Increasing the number of options can paradoxically lead to worse decisions, a phenomenon known as cognitive overload [1]. This happens when an individual decision-maker attempts to digest information exceeding its processing capacity. Highly integrated groups, such as social insect colonies, make consensus decisions that combine the efforts of many members, suggesting that these groups can overcome individual limitations [2–4]. Here we report that an ant colony choosing a new nest site is less vulnerable to cognitive overload than an isolated ant making this decision on her own. We traced this improvement to differences in individual behavior. In whole colonies, each ant assesses only a small subset of available sites, and the colony combines their efforts to thoroughly explore all options. An isolated ant, on the other hand, must personally assess a larger number of sites to approach the same level of option coverage. By sharing the burden of assessment, the colony avoids overtaxing the abilities of its members.

Nest site selection by Temnothorax ants exemplifies collective decision-making without well-informed leaders [5]. When a colony must find a new home, it can choose the better of two new sites even when no single ant assesses both. Instead, comparison emerges from a competition between recruitment efforts. Upon finding a site, an ant recruits nestmates to it with a probability that depends on the site’s quality, as determined by entrance diameter, cavity size, light level, and other features [6]. Her recruits make their own quality-dependent recruitment decisions, creating positive feedback that directs the colony towards the better nest. Consensus is further enhanced by a quorum rule that accelerates recruitment once a site’s population has surpassed a threshold [5].
Supplemental Information: Threat Modulates Perception of Looming Visual Stimuli

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Supplemental Experimental Procedures

Experiment 1

Participants

Thirty members of the Birkbeck community (14 female) between 18 and 56 years of age participated for payment or course credit. Participants were generally right-handed as assessed by the Edinburgh Inventory \((M: 81.2, \text{ range: } -61.9 – 100) [1]\). Participants reported normal or corrected-to-normal vision. Procedures were approved by the local ethics committee.

Stimuli

Stimuli were 160 color photographs found on the internet, 40 from each of the four categories (snakes, spiders, butterflies, and rabbits). Images were cropped and resized using Adobe Photoshop CS5 (Adobe Systems, San Jose, CA). This resulted in images (400 pixels wide, 250 pixels high) in which the animal took up the entire image. Backgrounds from the original photographs were replaced with a homogenous grey color (identical to the background of the experimental script).

Procedure

Participants sat at a table approximately 40 cm in front of a 19-inch monitor (75 Hz refresh rate). Stimulus presentation and data collection were controlled by a custom MATLAB (Mathworks, Natick, MA) script. On each trial, the stimulus increased in size across 75 frames (i.e., one second), consistent with one of five time-to-collisions (3.0, 3.5, 4.0, 4.5, and 5.0 s after the onset of the first frame). The width of the stimulus on the first frame was either 400 or 500 pixels (15.1° or 18.9°
visual angle), giving the impression that it was at two different distances. Starting image size was manipulated so that actual time-to-collision was not perfectly correlated with the size of the image on the final frame. After the 75th frame, the image was replaced by a grey background.

There were a total of 320 trials divided into 8 blocks of 40 trials each. Each block included one repetition of each combination of time-to-collision (5 levels), stimulus category (4 levels), and initial image size (2 levels). The order of trials within each block was randomized. The 40 images from each category were randomly assigned to trial types and each image was used exactly twice for each participant. After the participant responded on each trial, the next trial began after a random inter-trial interval of 300-800 ms.

Participants were all instructed that they would see objects expanding in size as if they were approaching and that they would disappear after one second. They were told that their task was to imagine the object continuing to approach at the same rate and to press the button when they judged that the object would have made contact with their body.

As described in the main paper, fear ratings for each of the four categories were collected by modifying the Fear of Spiders Questionnaire [2]. The 18 items on this questionnaire ask participants to indicate their agreement or disagreement with statements indicating fear or anxiety related to spiders. Example items include: “If I saw a spider now, I would feel very panicky.” and “I now would do anything to try to avoid a spider.” The 18 statements were modified for each of the other stimulus categories by replacing the word ‘spider’ with either ‘snake’, ‘butterfly’, or ‘rabbit’. Participants rated their agreement or disagreement with each statement using a 7-point Likert scale, where a score of +3 indicated strong agreement with the statement (i.e., high levels of fear) and -3 indicated strong disagreement (i.e., low levels of fear). The 72 items were presented in random order using a custom MATLAB script.
Fear Ratings

Unsurprisingly, mean fear ratings were higher for snakes (-.11) and spiders (-.41) than for butterflies (-2.18) and rabbits (-2.23), providing a manipulation check on our modulation of how threatening the different types of stimuli were. Fear ratings for snakes and spiders were strongly correlated, $r(29) = .668, p < .0001$, as were ratings for butterflies and rabbits, $r(29) = .868, p < .0001$. Thus, the two threatening and the two non-threatening stimuli were collapsed for further analyses.

Time-to-Collision Judgments

For each participant, Z-scores were calculated for time-to-collision judgments, separately for each level of actual time-to-collision. Trials with Z-scores greater than +3 or less than -3 were considered outliers and excluded from analyses (0.73% of trials excluded). An analysis of variance (ANOVA) was run on mean time-to-collision judgments including actual time-to-collision (3.0, 3.5, 4.0, 4.5, 5.0 s), stimulus category (threatening, non-threatening), and initial stimulus size (400, 500 pixels wide) as within-subjects factors. As reported in the main paper, there were clearly significant effects of actual time-to-collision (indicating that judgments increased monotonically with actual times) and of stimulus category (with judgments being reduced for threatening compared to non-threatening stimuli). There was no significant interaction between these factors, $F(4, 112) = 0.38, p > .50$.

There was also a significant effect of initial stimulus size, $F(1, 28) = 35.57, p < .0001$, with shorter judgments following presentation of larger than smaller images (3.945 vs. 4.130 s). This bias presumably reflects interpretation of the larger stimulus as being closer to the participant.

Participants have knowledge about the typical size of each of the types of stimulus we presented, meaning that familiar size can serve as a cue to perceived actual distance. Recent results have, in
fact, found that familiar size affects perceived time-to-collision with objects perceived as larger judged to arrive sooner than those perceived as smaller [3]. The present results suggest, similarly, that stimuli perceived to start closer to the observer are underestimated relative to those perceived to start farther away.

There were no other significant main effects or interactions.

**Experiment 2**

This experiment was similar to Experiment 1 with the exception that scrambled versions of each of the images were also used to control for any incidental visual characteristics of the stimuli.

*Participants*

An additional twelve people (8 female) between 18 and 43 years of age participated for payment or course credit. Participants were generally right-handed (M: 65.3, range: -91.6 – 100). Participants reported normal or corrected-to-normal vision.

*Stimuli*

Stimuli were the same 160 images used in Experiment 1, plus scrambled versions of each of those images. Scrambled images were made using a custom MATLAB script by dividing each image into 1000 10-pixel by 10-pixel tiles whose position was randomized.

*Procedure*

Procedures were the same as Experiment 1 with a total of 320 trials divided into 8 blocks of 40 trials each. Whereas in Experiment 1 each image was displayed twice, to accommodate the scrambled images in this experiment, each image was presented exactly once. Scrambled and non-scrambled images were randomly ordered across the eight blocks.
Time-to-Collision Judgments

Outliers were excluded as in Experiment 1 (0.99% of trials). Results are shown in Supplemental Figure 1. An ANOVA was run on mean time-to-collision judgments including stimulus type (scrambled, non-scrambled), actual time-to-collision (3.0, 3.5, 4.0, 4.5, 5.0 s), stimulus category (threatening, non-threatening), and initial stimulus size (400, 500 pixels wide) as within-subjects factors.

As in Experiment 1 there were significant main effects of actual time-to-collision, $F(4, 44) = 20.08$, $p < .0001$, initial stimulus size, $F(1, 11) = 8.86$, $p < .02$, and stimulus category $F(1, 11) = 7.26$, $p < .05$. There was also a significant main effect of stimulus type, $F(1, 11) = 10.56$, $p < .01$, which was modulated by a marginally-significant interaction of stimulus type and stimulus category, $F(1, 11) = 4.17$, $p = .066$, and a three-way interaction between stimulus type, stimulus category, and initial stimulus size, $F(1, 11) = 8.51$, $p < .02$.

To explore the significant three-way interaction, we ran two separate ANOVAs for non-scrambled and for scrambled images. The ANOVA on non-scrambled images revealed a significant main effect of stimulus category $F(1, 11) = 6.93$, $p < .05$, replicating the finding that threatening stimuli are underestimated compared to non-threatening stimuli. In contrast, for scrambled images, there was no main effect of stimulus category $F(1, 11) = 0.00$, n.s., suggesting that the effect found in Experiment 1 is not driven by stimulus related characteristics.

To further explore the three-way interaction from the omnibus ANOVA, we ran separate ANOVAs for threatening and non-threatening stimuli. The ANOVA on threatening stimuli revealed a significant main effect of stimulus type, $F(1, 11) = 9.06$, $p < .02$, indicating that for threatening stimuli there was a significant underestimation of non-scrambled relative to scrambled images.
In contrast, for non-threatening stimuli there was no main effect of stimulus type $F(1, 11) = 0.74$, *n.s.*, indicating that, for this stimulus category, there was no significant difference between scrambled and non-scrambled images. This pattern suggests that the difference in time-to-collision judgments between threatening and non-threatening stimuli is driven primarily by responses to the threatening stimuli.

**Supplemental Figure 1**: Results from Experiment 2. The left panel shows results from the Non-Scrambled condition, which replicate the key findings from Experiment 1 that the threatening stimuli appear to arrive sooner than the non-threatening stimuli. The right panel shows results from the Scrambled condition, in which the difference between threatening and non-threatening disappeared.

**Experiment 3**

This experiment investigated the possibility that the effects seen in Experiments 1 and 2 could result from non-specific responses to seeing threatening stimuli, such as changes in arousal. The same images used in Experiment 1 were presented statically for one second as primes, and time-to-
collision judgments were made about a looming blue circle which appeared immediately after each picture.

Participants

As additional twelve people (8 female) between 19 and 51 years of age participated. Participants were generally right-handed (M: 93.3, range: 66.6 – 100). Participants reported normal or corrected-to-normal vision.

Stimuli

Stimuli were the same as those in Experiment 1. In addition, we made an image of a blue circle, which was used for time-to-collision judgments.

Procedure

The procedures were similar to Experiment 1 except that the photographs of the stimulus categories were presented statically as primes for one second and then disappeared. Immediately after each image disappeared, we presented a blue circle, which expanded in size for one second, like the images in Experiments 1 and 2. The width of the blue circle on the first frame was either 400 or 500 pixels (15.1° or 18.9° visual angle). There were a total of 320 trials divided into 8 blocks of 40 trials each.

Time-to-Collision Judgments

Outliers were excluded as in Experiment 1 (0.78% of trials). Results are shown in Supplemental Figure 2. As in the other experiments, there were significant main effects of actual time-to-collision, $F(4, 44) = 14.34, p < .0001$, and initial stimulus size, $F(1, 11) = 22.19, p < .001$. Critically, however, there was no significant effect of prime type, $F(1, 11) = .54, n.s.$, indicating that the presentation of threatening or non-threatening primes before the looming stimulus did not affect
judgments of its time-to-collision. This result suggests that the effect seen in Experiments 1 and 2 is not simply due to non-specific effects of the threatening stimuli (e.g., arousal).

Overall, time-to-collision judgments in Experiment 3 were substantially longer than in the other two experiments. While unpredicted, there are several differences between the experiments that may account for this. One possibility is real objects (e.g., photographs of animals as in Experiments 1 and 2) may be perceived as arriving more quickly than abstract geometric forms (e.g., the blue circle used in this experiment). Alternatively, the presence of priming stimuli might have distracted participants from their primary task, resulting in delayed responses. This is a potentially interesting issue for future research.

**Supplemental Figure 2**: Results from Experiment 3. The presence of threatening vs. non-threatening primes had no apparent effects on judged time-to-collision of the looming blue circle.
References

