Deconstructing the Snake: The Relative Roles of Perception, Cognition, and Emotion on Threat Detection

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Previous research has documented a propensity for rapid detection of various threats like snakes and spiders in human adults, children, and even infants. The current research presents a controlled, systematic investigation of the mechanisms by which humans quickly detect threat. In 3 experiments, we examine the unique and interacting roles of low-level perceptual cues, cognitive factors such as threatening labels, and emotional state to rapid threat detection. Across studies, low-level perceptual features of snakes—namely, curvilinear shapes—consistently elicited rapid detection. Using threatening labels (Experiment 2) facilitated detection marginally more, and a fearful emotional induction (Experiment 3) facilitated detection even further. Collectively the results offer a more complete picture of the mechanisms by which humans quickly perceive threat, suggesting that rapid threat detection can result from several individual and interacting factors, including perceptual, cognitive, and emotional.

Keywords: detection, threat, attention, snakes, spiders

For decades, researchers have investigated how individuals respond to threat. A substantial body of work has since reported a striking phenomenon: Human adults rapidly detect the presence of threatening stimuli more quickly than a variety of nonthreatening stimuli. More specifically, adults and even preschool children detect snakes and spiders more quickly than a variety of benign stimuli, such as flowers, mushrooms, frogs, and cockroaches (Flykt, 2005, 2006; Hayakawa, Kawai, & Masataka, 2011; Lipp, 2006; Lipp & Derakshan, 2005; Lipp, Derakshan, Waters, & Logies, 2004; Lipp & Waters, 2007; LoBue, 2010; LoBue & DeLoache, 2011; LoBue & DeLoache, 2008; Masataka & Shibasaki, 2012; Öhman, Flykt, & Esteves, 2001; Purkis & Lipp, 2007; Soares, Esteves, Lundqvist, & Öhman, 2009; Tipples, Young, Quinlan, Broks, & Ellis, 2002). They also detect threatening or angry faces more quickly than happy, neutral, or even sad faces (Calvo, Avero, & Lundqvist, 2006; Eastwood, Smilek, & Merikle, 2001; Esteves, 1999; Fox et al., 2000; Hansen & Hansen, 1988; LoBue, 2009; Lundqvist & Öhman, 2005; Öhman, Lundqvist, & Esteves, 2001; Schubo, Gendolla, Meinecke, & Abele, 2006; Tipples, Atkinson, & Young, 2002; Williams, Moss, Bradshaw, & Mattingly, 2005). This basic finding has been replicated using various stimuli, different paradigms, and even across different species (e.g., Shibasaki, & Kawai, 2009), demonstrating a clear bias for threat in visual detection tasks. Even infants have shown a propensity to quickly orient to snakes, spiders, and threatening

faces—more quickly than they orient to a variety of benign stimuli (LoBue & DeLoache, 2010; Rakison & Derringer, 2008).

Despite extensive study of the parameters of threat detection, evidence about the mechanisms that drive this phenomenon is somewhat mixed. Some researchers have argued that low-level perceptual features commonly found in threatening stimuli might be detected very quickly by the human visual system (Calvo & Marrero, 2009; Cave & Batty, 2006; Horstmann, 2009; Horstmann, Heumann, & Borgstedt, 2006; LoBue, 2013; LoBue & Rakison, 2013; LoBue, Rakison, & DeLoache, 2010). Several studies have shown that the advantage for angry faces, for example, is driven by specific features of the faces, such as perceptual properties of the eyes or the mouth (Calvo & Nummenmaa, 2008; Coelho, Cloete, & Wallis, 2010; Fox & Damjanovic, 2006; Lundqvist, Esteves, & Öhman, 1999; Lundqvist & Öhman, 2005). Further, such an advantage can be eliminated by manipulating other simple features of the face, such as changing the outline of face stimuli or by scrambling its components (Becker, Horstmann, & Remington, 2011; Horstmann, Becker, Bergmann, & Burghaus, 2010).

Although this work suggests that specific features of threatening stimuli might drive rapid detection, humans detect a variety of perceptually dissimilar categories of threat particularly quickly, including snakes, spiders, angry faces, and even guns and knives (Blanchette, 2006; Brosch & Sharma, 2005; LoBue, 2009, 2010; LoBue & DeLoache, 2008; Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001). Thus, others have argued that threat-relevance, or the *threatening message* produced by these stimuli is what facilitates detection (Eastwood & Smilek, 2005; Eastwood, Smilek & Merikle, 2001, 2003; Lipp & Derakshan, 2005; Lipp & Waters, 2007; Lundqvist & Öhman, 2005; Öhman, Lundqvist, & Esteves, 2001). Indeed, the more aversive or negative participants rate threatening stimuli, the faster participants detect them (Beaver, Mogg, & Bradley, 2005; Masataka, Hayakawa, & Kawai, 2010). Further, some studies have shown that

there is no advantage for the detection of angry faces when features of the faces are scrambled (Fenske & Eastwood, 2003), contextual information is removed (Schubo, Gendolla, Meinecke, & Abele, 2006; Tipples, Atkinson, & Young, 2002), or the faces are inverted, which generally results in impaired holistic face processing (Eastwood, Smilek, & Merikle, 2001, 2003; Fox et al., 2000).

Together, these findings do not present a clear answer to the question of whether threat relevance or perceptual features of threatening stimuli drive their rapid detection. Instead, this work suggests that performance on threat detection tasks may in fact vary based on a number of factors (Frischen, Eastwood, & Smilek, 2008). Here we propose that threat detection is not driven by perceptual or emotional factors alone; instead, rapid threat detection can be driven by a number of individual and interacting factors, and can vary based on the number of threat-relevant cues provided (Frischen, Eastwood, & Smilek, 2008).

First, we examine whether very simple low-level perceptual cues—in the absence of any threat-relevant information—are sufficient in producing an advantage in detection. Classic work in visual perception has indeed suggested that some simple shapes, such as curvilinear lines, might be easier to detect than others (Treisman & Gelade, 1980; Wolfe, Yee, & Friedman-Hill, 1992). Further, research with both adults and children has confirmed that the low-level features of threatening stimuli, such a snake's curvilinear shape, or an angry face's "V" shaped brow are sufficient in eliciting rapid detection in both adults and in children (Larson, Aronoff, & Stearns, 2007; LoBue & De-Loache, 2011; LoBue & Larson, 2010). In the first set of experiments, we will examine the role of perceptual biases for very simple shapes in detection.

Second, we examine whether knowledge or expectations about threatening stimuli also play a role in detection (Frischen, Eastwood, & Smilek, 2008). For example, seeing a threatening stimulus might prime knowledge about its threatening properties (e.g., snakes bite). Recent studies have shown that both adults and children can *learn* to quickly detect a previously neutral stimulus by associating it with it threatening properties (Field, 2006a, 2006b; Koster et al., 2004). For example, in two separate studies, researchers provided children between the ages of 6 and 9 (Field, 2006a) and 8 and 10 (Field, 2006b) with negative verbal information about one of two novel animals. After learning negative information about one of the animals, children detected it more quickly in a visual dot-probe task than they detected the other animal (Field, 2006a, 2006b). These studies suggest that knowledge about the nature of threatening stimuli might make us more vigilant in visual search tasks. In our second experiment, we will examine the role of cognition—or more specifically, threat-relevant information about the target stimuli—in detection.

Finally, we will also examine the possibility that arousal or a heightened emotional state evoked by threatening stimuli can also drive rapid detection. Indeed, both adults and children with specific phobias or clinical anxiety detect the object of their fear more quickly than do nonfearful participants (Byrne & Eysenck, 1995; Derryberry & Reed, 2002; Flykt & Caldara, 2006; Fox, Russo, & Dutton, 2002; Gilboa-Schechtman, Foa, & Amir, 1999; LoBue & Pérez-Edgar, in press; Mogg & Bradley, 2002; Öhman et al., 2001; Pishyar, Harris, & Menzies, 2004; Pollak & Kistler, 2002). Thus,

heightened feelings of arousal or anxiety evoked by seeing a threatening stimulus may make participants more vigilant. In a third and final experiment, we will examine the role of emotional state on detection.

The current work is the first systematic investigation of the relative roles of perception, cognition, and emotion on threat detection. In Experiment 1, we examine whether adults have perceptual biases for the low-level features common in some threats by comparing the detection simple curvilinear "snake-like" shapes with similar rectilinear shapes. In Experiment 2, we examine the role of cognition (i.e., knowledge about the threat-relevant properties of a stimulus) by testing whether using threatening labels facilitates detection. In Experiment 3, we focus on the contribution of emotional state to rapid threat detection by priming adults with emotional or neutral videos before asking them to complete a detection task. Finally, across studies and experimental conditions we use the same simple curvilinear and rectilinear shapes as the target stimuli so that we can examine potential interactions between perceptual, cognitive, and emotional cues.

General Method

Previous research has already suggested that low-level perceptual features common of certain threatening stimuli might play a critical role in their rapid detection (LoBue & DeLoache, 2011; LoBue & Larson, 2010). However, the previous research described above used complex, real photographs of snakes, spiders, and neutral distracter stimuli. Although using realistic stimuli is important for ecological validity, they are complex and not easily controlled. The current experiments used very simple stimuli. Further, although previous work has shown rapid detection of various categories of threat (snakes, spiders, and angry faces), here we concentrate on only one exemplar, snakes, as these are the most commonly used fear-inducing stimuli in previous work (see Öh-man & Mineka, 2001 for review). Despite this relatively narrow focus, curvilinear shapes are characteristic of other threats in nature. For example, spiders' legs are made up of curved config-urations much like snakes' (Rakison & Derringer, 2008). Thus, findings regarding simple curvilinear shapes might contribute to the rapid detection of other threats as well.

Using a touch-screen paradigm (LoBue & DeLoache, 2008), across all experiments, adults were presented with 3×3 matrices of photographs and asked to touch a target on the screen as quickly as possible. The touch-screen paradigm was used in lieu of the more traditional button-press method because the touch-screen method is more appropriate for a wide age range (3-year-olds through adults). This will allow for future developmental investi-gations of our research questions using the same methodology.

Pretests

As mentioned above, the goal of the current work was to examine the role of low-level perceptual features of threatening stimuli in detection. We chose to use very simple curvilinear and rectilinear stimuli in each of the experiments (see Figure 1). Two pretests were run to ensure that the stimuli were appro-priate. First, we sought to confirm that curvilinearity is indeed a recognizable and salient feature of snakes. We asked a sample
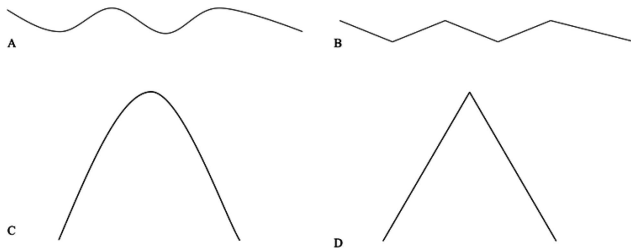
Figure 1. Target curvilinear and rectilinear stimuli used in Experiments 1 (A and B, top) and Experiment 1a (C and D, bottom).

of 24 adults (six male, 18 female; $M = 21$ years) whether they would describe a snake and a caterpillar as "curvy." Although only 50% of participants said that caterpillars are curvy, 75% of participants said that snakes are curvy. A binomial logistic regression comparing participants' responses with snakes versus caterpillars was approaching significance, $\chi^2 = 3.2$, $p = .072$. Thus, although these results do not necessarily demonstrate that curviness is perceptually diagnostic of snakes, they do provide some evidence that adults perceive curviness as a conceptual characteristic of snakes.

Second, we sought to confirm that the simple target stimuli used across studies were neutral in valence. Previous research has suggested that participants have preferences for curvilinear versus rectilinear shapes (Bar & Neta, 2006, 2007). Similarly, others have suggested that adults might assign a positive or negative valence to simple shapes or colors (McMenamin & Marsolek, 2013; Mc-Menamin et al., 2012). As any such preconceived preferences might affect our results, we first sought to determine whether our stimuli already carried a positive or negative valence. A second sample of 24 adults (half male, half female; $M = 21$ years) were presented with a survey that featured images of the stimuli used in Experiment 1 (Figure 1, A and B) and Experiment 1a (Figure 1, C and D). Participants were asked to rate the valence of each stimulus on a scale ranging from -2 (*very negative*), -1 (*negative*), 0 (*neutral*), 1 (*positive*), and 2 (*very positive*). There was a trend for rectilinear shapes to be rated more negatively than curvilinear shapes. This is consistent with the previous research suggesting that angular forms are perceived as more negative than are curvilinear forms (Bar & Neta, 2006, 2007). However, in a series of one-sample *t* tests, none of the stimuli were rated significantly differently from zero (Curvilinear A: $M = 0.21$, $t = 1.0$, $p = .328$;

Rectilinear A: $M = -0.29$, $t = -1.9$, $p = .070$; Curvilinear B: $M = 0.04$, $t = 0.2$, $p = .840$; Rectilinear B: $M = 0.26$, $t = 1.1$, $p = .299$). Further, there were no significant differences between the valence ratings of the curvilinear and rectilinear lines used in Experiments 1, $t = 2.4$, $p = .078$, or the curvilinear and rectilinear lines used in Experiment 1a, $t = -0.97$, $p = .151$. Thus, the simple stimuli used here across experiments were neutral.

Materials

The stimuli for each experiment consisted of 325×245 pixel images. For each experiment, there were two categories of images that were arranged in 3×3 matrices, with one target picture from one category and eight distracter pictures from another category. The specific images used for each experiment are described below. A 19-inch GVision touch-screen LCD monitor was used to present each matrix. The matrices spanned to fit the screen (12 in. $\times$ 15 in.), and the images within each matrix measured 4.5 in. $\times$ 3.75 in. (see Figure 2). Each target appeared in each of the nine positions in the matrix two or three times. One stimulus order was created by randomly arranging matrices, and a second order was used that was the reverse of the first.

Procedure

Each participant was seated in front of the touch-screen monitor (approximately 40 cm from the base of the screen). First, a set of seven practice trials was given to teach the participant how to use the touch-screen. On the first two trials, a single picture appeared on the screen. The first picture was from the target category and the second from the distracter category. Participants were asked to touch each picture on the screen. In the next two trials, participants were presented with one target and one distracter picture and asked to touch only the target picture. The last three practice trials consisted of different nine-picture matrix. Participants were told that for each trial, the task was to find the "X" (target) among "Y" (distracters) as quickly as possible, and touch it on the screen. All participants learned the procedure quickly.

In a series of 24 test trials, a matrix containing one target and eight distracters was presented on each trial. In between trials, a gray screen appeared that read, "Are you ready?" To ensure participants' attention to the middle of the screen at the start of each trial, participants were asked to touch a large emoticon under the text to advance to the next trial. Latency was automatically
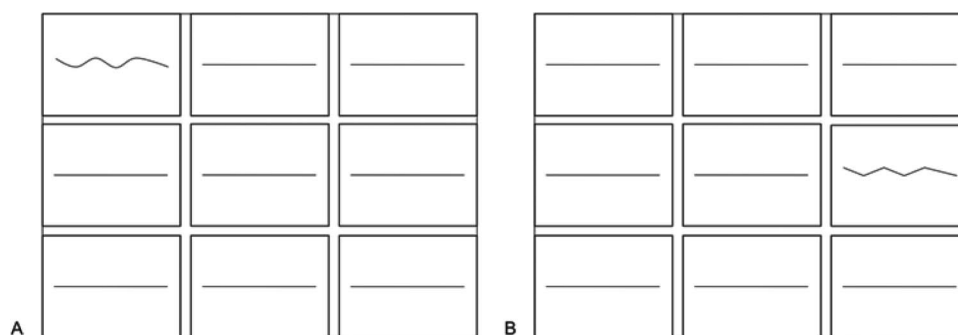

Figure 2. Sample matrices for Experiments 1, 2, 3: (A) Curvilinear target (B) Rectilinear target.

recorded from the onset of the matrix to when the participant touched one of the images on the screen.

Participants

Forty-eight undergraduate students from the Rutgers University-Newark campus participated in Experiment 1 ($M = 22$ years), an additional 48 undergraduates participated in Experiment 1a ($M = 20$ years), and an additional 48 in Experiment 1b ($M = 20$ years). Experiments 2 and 3 have twice as many experimental conditions as Experiments 1, 1a, and 1b, so twice as many participants (N = 96) were tested in each (Experiment 2, $M = 20$ years; Experiment 3, $M = 21$ years). Ten additional participants were eliminated across all studies for inattentiveness during the task (e.g., looking at cell phone in the middle of the study, N = 4) or experimenter error (N = 6). In all studies, half of the participants were male and half were female. They were all recruited from the Rutgers University human subjects participant pool and received partial credit toward their general requirements for psychology courses. The Rutgers University Institutional Review Board approved all procedures, and all participants signed an informed consent.

Analyses

Following standard procedures for visual search tasks, only trials in which the correct target was selected were counted. Participants rarely erred (only 15 errors were made across all experiments), and errors did not vary by target. Mixed Effects ANOVAs were used across studies to analyze trial-level data. As participants tend to improve on detection tasks over the course of many trials and multiple conditions, trial and subject were used as random effects to account for individual variations in a participants' behavior over the course of trials, reducing the potential for error (Baayen, Davidson, & Bates, 2008; Bagiella, Sloan, & Heitjan, 2000; Gueorguieva & Krystal, 2004).

Experiment 1

The goal of Experiment 1 was to examine whether adults have perceptual biases for the low-level features that make up some threatening stimuli. Snakes, in particular, can be characterized by their curvilinear shapes. Indeed, previous findings have shown that children and adults quickly detect stimuli that are shaped like snakes, such as coiled wires and ropes (LoBue & DeLoache, 2011). However, these stimuli were complex and not well controlled. Thus, in Experiment 1, simple curvilinear shapes were compared to equally simple rectilinear shapes.

In two counterbalanced tasks, adults participated in the touch-screen detection procedure described above. In one task, they detected a curvilinear (snake-like) shape (see Figure 2, A) among eight distracters (straight lines). In the second task, they detected a noncurvy rectilinear shape (see Figure 2, B) among the same eight distracters (within-subjects). Each shape was approximately 3.5 in. in length. The targets were not labeled in either condition, participants were simply told, "Find the ones that look like this," while the experimenter pointed out the target stimulus during warm-up trials. Latency to detect each target was measured.

A Mixed Effects ANOVA on the latency to touch the target yielded a main effect of target, $F(1, 2322) = 16.4, p < .000$. As
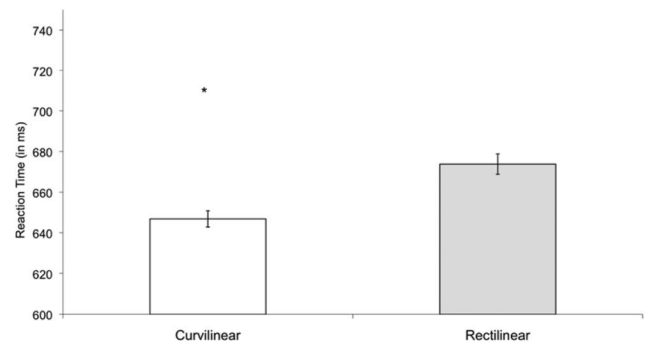

Figure 3. Average latencies to detect targets in Experiment 1.

predicted, the curvilinear targets ($M = 647$ ms) were detected more quickly than the rectilinear targets ($M = 674$ ms; see Figure 3).

Experiment 1a

The results of Experiment 1 suggest that adults have low-level perceptual biases for the detection of simple curvilinear shapes. It is possible, however, that the curvilinear lines used in Experiment 1 too closely resembled snakes and brought to mind knowledge about snakes' threatening properties. Thus, thoughts about snakes could have contributed to the results. Experiment 1a attempts to control for this possibility by presenting participants with targets that consisted of a single curve or an analogous rectilinear shape (see Figure 4, top). The single curve used in Experiment 1a looks less like a snake than the curvilinear shape used in Experiment 1. Thus, if the results of Experiment 1 can be replicated with a single curve, we can conclude that rapid detection can indeed be driven by the curvilinear nature of a stimulus, and not necessarily because it brings to mind any threatening properties. Thus, Experiment 1a used the same method as Experiment 1 with the simplified curvilinear and rectilinear targets shown in Figure 4 (top).

A Mixed Effects ANOVA on the latency to touch the target for Experiment 1a yielded a main effect of target $F(1, 2224) = 18.4, p < .000$. Like in Experiment 1, the curvilinear targets ($M = 610$ ms) were detected more quickly than the rectilinear targets ($M = 639$ ms).

Experiment 1b

The results of Experiment 1a confirm the results of Experiment 1, suggesting that simple curvilinear lines are detected more quickly than rectilinear lines. However, another possibility is that the curvilinear targets were easier to detect than the rectilinear targets in Experiments 1 and 1a because the distracters were all straight (rectilinear) lines, thus making the curvilinear targets easier to find. Experiment 1b attempts to control for this possibility by presenting participants with the same curvilinear and rectilinear targets used in Experiment 1 among small circular (curvilinear) distracters. Experiment 1b used the same method as Experiment 1 with curvilinear distracters shown in Figure 4 (bottom).

A Mixed Effects ANOVA on the latency to touch the target for Experiment 1b yielded a main effect of target $F(1, 2273) = 5.2, p = .023$. Like in Experiment 1a, the curvilinear targets ($M = 631$
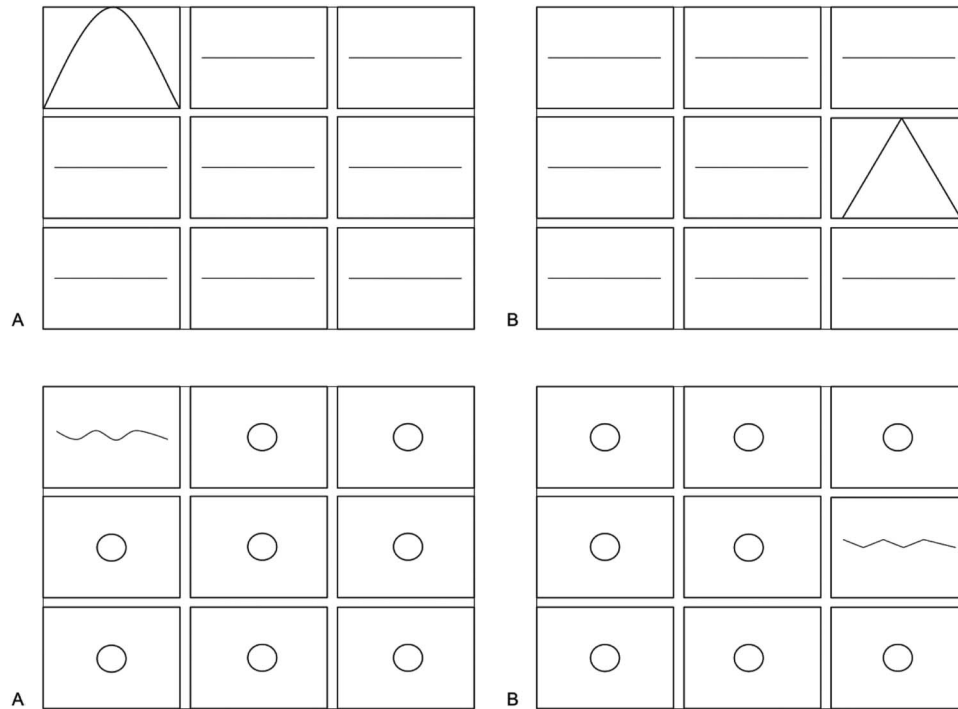
Figure 4. Sample targets for Experiments 1a (top): (A) Curvilinear target (B) Rectilinear Target, and Experiment 1b (bottom): (A) Curvilinear target (B) Rectilinear Target.

ms) were detected more quickly than the rectilinear targets ($M = 646$ ms).

Experiment 2

Together, the results of Experiments 1, 1a, and 1b demonstrate that adults do indeed detect simple curvilinear shapes more quickly than similar rectilinear shapes. These findings suggest that previous work reporting rapid detection of threats like snakes and spiders might be due to biases for the detection of some very simple shapes, and not necessarily because of the threat-relevance of the stimuli. However, biases for simple shapes may not tell the whole story, as humans detect a variety of perceptually dissimilar categories of threat very quickly. An alternative possibility is that knowledge about the nature of threatening stimuli might contribute to their rapid threat detection as well. In previous studies, adults and young children were shown real photographs of snakes. Simply knowing that the target stimulus is a snake could have brought to mind a snake's threatening properties (e.g., they bite). Thus, when using real photographs of snakes, perceptual features and knowledge about the target stimuli are confounded. Experiment 2 explores the separate and interacting roles of perception and cognition in threat detection by examining the effect of labeling on detection.

Experiment 2 used the same procedure and stimuli from Experiment 1 (see Figure 2) with one exception: For half of the participants, the curvilinear targets were labeled as "snakes" (threatening) and the rectilinear targets were labeled as "caterpillars" (nonthreatening), and for the other half, the rectilinear targets were labeled as "snakes" and the curvilinear targets

were labeled as "caterpillars." Condition and task order were counterbalanced across participants. If rapid detection of snakes is based solely on low-level perceptual biases, a main effect of target shape is expected. However, if cognition or knowledge about snakes contributes to their rapid detection, a main effect of label, or a label by target shape interaction is expected.

A 2 (target) $\times$ 2 (label) Mixed Effects ANOVA on the latency to touch the target revealed a main effect of target $F(1, 4525) = 11.5$, $p = .001$, with a target by label interaction that was approaching significance, $F(1, 4525) = 3.5$, $p = .062$. Like in Experiment 1, the curvilinear targets ($M = 645$ ms) were detected more quickly than the rectilinear targets ($M = 660$ ms). The marginal target by label interaction indicated that when targets were given a snake label, participants were significantly faster to detect curvilinear targets ($M = 641$ ms) than rectilinear targets ($M = 664$ ms), $F(1, 2254) = 14.3$, $p < .000$, whereas there was no difference between detection of targets with the caterpillar label (curvilinear, $M = 650$ ms; rectilinear, $M = 656$ ms), $F(1, 2248) = 1.1$, $p = .294$ (see Figure 5). There were also no differences in detecting curvilinear targets when given the "snake" ($M = 641$ ms) versus "caterpillar" label ($M = 650$ ms), $F(1, 2277) = 2.2$, $p = .141$, or in detecting rectilinear targets when given the "snake" ($M = 664$ ms) versus "caterpillar" label, ($M = 656$ ms), $F(1, 2271) = 1.3$, $p = .253$.

It is noteworthy that there was no advantage for the curvilinear target when given a nonthreatening label. It is possible that providing additional irrelevant or nonthreatening information does not facilitate, but instead, slows down detection. This begs the question of whether labeling the curvilinear shape a
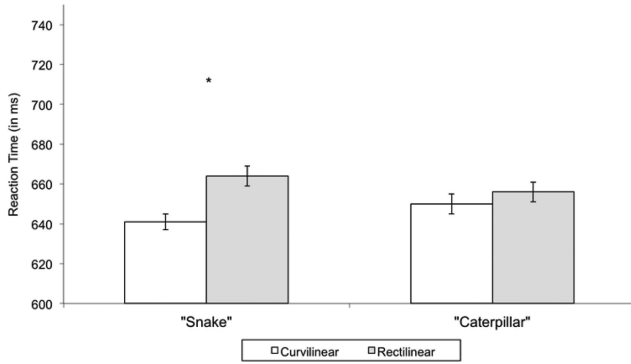
Figure 5. Average latencies to detect targets in Experiment 2.

"snake" did indeed decrease reaction time (RT), or conversely, whether applying the "caterpillar" label increased RT. To answer this question, we used the data from Experiment 1 as a baseline and ran a series of independent samples t tests to compare each condition in Experiment 2 to the curvilinear and rectilinear conditions in Experiment 1. The t tests indicated that adding the "caterpillar" label did not decrease RT from baseline in the curvilinear condition, $t = -0.424$, $p = .671$; in fact, it increased RT in the rectilinear, $t = 2.460$, $p = .014$ condition when compared with baseline. Interestingly, although there was a significant difference between detecting curvilinear and rectilinear targets when given a snake label, neither differed from baseline (curvilinear, $t = 1.084$, $p = .279$; rectilinear, $t = 1.386$, $p = .166$).

Together, this pattern of results (seen in Figure 6) suggests that the "snake" label did facilitate detection for curvilinear targets versus rectilinear targets, but only slightly, and not significantly from baseline. Thus, there was some (albeit weak) evidence that threatening label paired with perceptually appropriate (curvilinear) targets gains some advantage in detection.
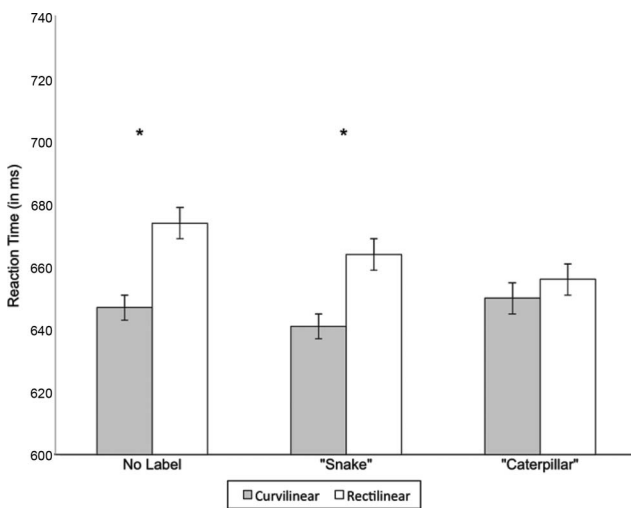

Figure 6. Average latencies to detect targets in Experiment 2 compared with Experiment 1 (baseline).

Experiment 3

In addition to perception and cognition, emotional reactivity may also play a role in detecting threatening stimuli. In particular, seeing threatening stimuli might evoke an emotional response that heightens an individual's vigilance in detection tasks. Experiment 3 was designed to examine the possibility that a heightened emotional state might lead to rapid detection. The procedure and stimuli for Experiment 3 were identical to that of Experiment 1 with two exceptions. First, participants received a nonemotional (neutral) or emotional (fearful) induction before performing the detection task. Half of the participants watched a 1-min emotion-inducing clip from *The Shining*, which in previous work, has been shown to consistently produce increases in fear (Rottenberg, Ray, & Gross, 2007). The other half watched a 1-min neutral clip from the same movie. Afterward, participants followed the same procedure described in Experiment 1, detecting curvilinear or rectilinear shapes (see Figure 2) in the touchscreen visual search procedure. As a manipulation check, participants were also given a standard survey asking them to describe how the movie clip made them feel (Rottenberg, Ray, & Gross, 2007). Second, the procedure was between-subjects instead of within-subjects to avoid potential order effects caused by the emotional induction. Thus, participants only performed one detection task, and they were randomly assigned to detect the curvilinear or rectilinear shapes, and randomly assigned to the fearful or neutral induction. All variables were counterbalanced across participants.

Results from the manipulation check confirm that participants reported more feelings of fear, $F(1, 91) = 86.9$, $p < .000$ and anxiety, $F(1, 91) = 38.0$, $p < .000$ when watching the fearful video than when watching the neutral video. A 2 (target) × 2 (video) Mixed Effects ANOVA on the latency to touch the target revealed a main effect of target $F(1, 2274) = 13.7$, $p < .000$, a main effect of video, $F(1, 2274) = 80.6$, $p < .000$, with a target by video interaction, $F(1, 2274) = 26.9$, $p < .000$. Confirming the findings above, participants detected the curvilinear targets ($M = 668$ ms) more quickly than the rectilinear targets ($M = 693$ ms). Further, participants detected targets after watching the emotional (fearful) video ($M = 650$ ms) more quickly than after the neutral video ($M = 710$ ms). Most importantly, the target by video interaction indicates that detection for the curvilinear target/emotional video ($M = 619$ ms) was significantly faster than detection of the rectilinear target/emotional video ($M = 680$ ms), $F(1, 1126) = 48.1$, $p < .000$; there was no significant difference between detection of the targets in the neutral video condition (curvilinear, $M = 716$ ms; rectilinear, $M = 706$ ms), $F(1, 1126) = 0.09$, $p = .334$ (see Figure 7).
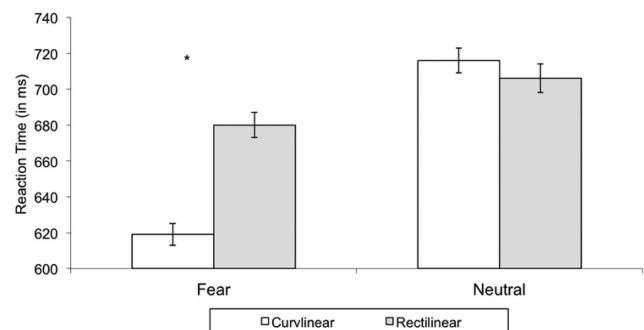

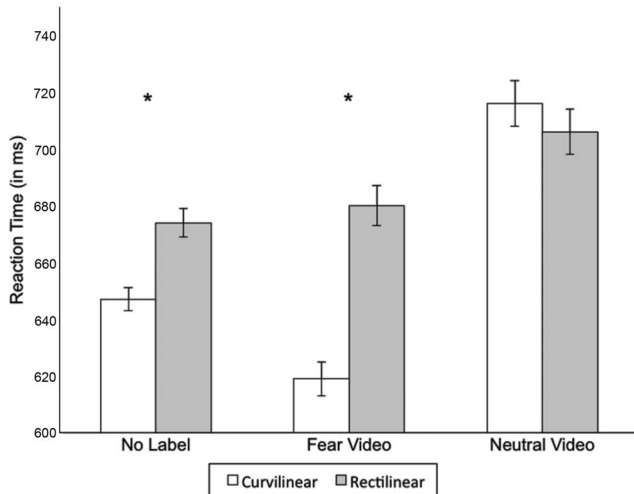*Figure 7.* Average latencies to detect targets in Experiment 3.

Figure 8. Average latencies to detect targets in Experiment 3 compared with Experiment 1 (baseline).

Similar to the results of Experiment 2, there was no advantage for the curvilinear targets after participants watched a neutral video. This again suggests that providing irrelevant or nonthreatening information might *slow* detection. To examine this issue further, we again used the data from Experiment 1 as a baseline comparison for each condition in Experiment 3. A series of independent samples *t* tests confirmed the results of the ANOVA, demonstrating a significant decrease in RT from baseline to the fear condition for curvilinear targets, $t = 3.857$, $p < .000$; there was no significant decrease from baseline for the rectilinear targets in the fear condition ($t = -0.712$, $p = .476$). Further, the results confirm a significant increase from baseline in both the neutral video conditions (curvilinear, $t = -8.790$, $p < .000$; rectilinear, $t = -3.512$, $p < .000$; see Figure 8). It is puzzling that the neutral video increased response time in both the curvilinear and rectilinear conditions. It is not clear why such results were found, but we found similar results in Experiment 2 (although in Experiment 2 the increase was not significantly different from baseline). Again, it is possible that providing additional irrelevant information uses
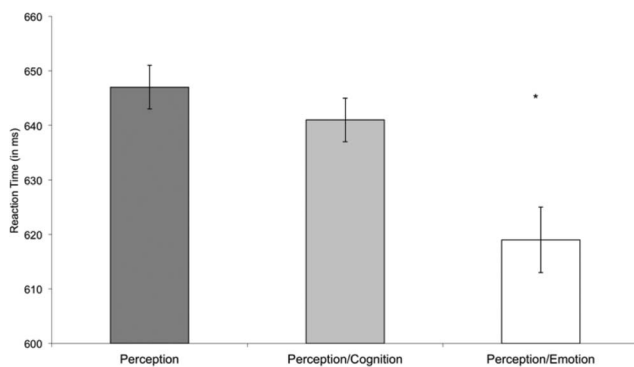

Figure 9. Average latencies to detect the curvilinear targets in Experiment 1 (Perception), the curvilinear targets matched with the snake label in Experiment 2 (Perception/Cognition), and the curvilinear targets matched with the fearful induction in Experiment 3 (Perception/Emotion).

cognitive resources that are then unavailable for the detection task. However, it is not clear exactly what cognitive processes the neutral movie clip triggers, and how they would interfere with performance on the detection task. This issue should be explored further in future research.

Together, the results of Experiment 3 demonstrate that an emotional induction has a strong effect on threat detection. Further, the combination of an emotional induction with a curvilinear target leads to enhanced detection, confirming that rapid threat detection is the result of the combination of several interacting factors.

Comparisons Across Experiments

The data presented here suggest that low-level perceptual cues, and curvilinear features in particular, are sufficient to elicit rapid detection. The results of Experiments 2 and 3 further suggest that cognition and emotion might play a role in further facilitating detection. One question that remains is whether the manipulations in Experiments 2 and 3 facilitated detection above and beyond the basic effect of curvilinearity, and whether each feature could play a potential additive role in threat detection. To investigate this question, a one-way ANOVA was done on latency to detect curvilinear targets from Experiment 1 (*perception*), curvilinear targets with a threatening ("snake") label from Experiment 2 (*perception/cognition*), and curvilinear targets with an emotional (fearful) induction from Experiment 3 (*perception/emotion*), yielding a significant result, $F(2, 2850) = 8.6$, $p < .01$. Post hoc comparisons indicated that participants were slowest when detecting a curvilinear line alone (Experiment 1; $M = 647$ ms); they were slightly faster (but not significantly) when a curvilinear line was presented with a threatening label (Experiment 2; $M = 638$ ms); and participants were fastest (significantly faster than the other two conditions, Tukey's HSD and Bonferonni, $p < .05$) when a curvilinear line was presented after an emotional induction (Experiment 3; $M = 619$ ms). This contrast is highlighted in Figure 9, and is suggestive that these three factors may play interacting roles in threat detection.

General Discussion

A substantial body of work has long established that various categories of threatening stimuli—including snakes, spiders, and angry faces—are detected more quickly than neutral or positive stimuli (Öhman & Mineka, 2001). The current work takes this research a step further by examining the mechanisms that drive rapid threat detection. In five experiments, we examined the relative roles of perception, cognition, and emotion on detection.

Experiments 1, 1a, and 1b demonstrate that humans have attentional biases for the low-level stimulus features that are characteristic of snakes—namely, their curvilinear shapes. In fact, across all five experiments, adults detected simple curvilinear shapes more quickly than equally simple rectilinear shapes. These results confirm the notion that humans may have low-level perceptual biases that draw attention to certain stimuli in the environment (LoBue, & Rakison, 2013; LoBue, Rakison, & DeLoache, 2010). These perceptual biases may have developed specifically for the detection of threats like snakes, or they may have developed for unknown reasons but still draw attention to shapes that are snake-like. Classic work in visual perception has suggested that curvilinearity

is a basic stimulus feature that "pops-out" in an array (Treisman & Gelade, 1980; Wolfe, Yee, & Friedman-Hill, 1992). Thus, the findings reported here might reflect a basic feature of the visual system that inadvertently draws our attention to snake-like stimuli.

Curvilinear features are represented in other threats as well, including spiders, and are highly represented in naturally occurring (as opposed to man-made) stimuli more generally. Lipp, Derakshan, Waters, and Logies (2004) reported a search advantage for all animals, not just threatening animals, so it is possible that curvilinear features facilitate the detection of various stimuli and is not specific to threats. Snakes, particularly coiled snakes, are made up of several curved shapes, which might make them easier to detect than other stimuli, even other animals like frogs and caterpillars (LoBue & DeLoache, 2008). Future research can investigate whether there is a relationship between speed of detection and the number of curvilinear forms in a particular stimulus. Overall, the data reported here suggest that rapid detection can be elicited in the absence of any threat-relevant features or information—a simple curvilinear figure is sufficient to elicit the same type of rapid responding reported for threats.

As mentioned above, perceptual features, however, may not necessarily explain the entire phenomenon, as humans detect a variety of perceptually dissimilar categories of threat very quickly, including snakes, spiders, angry faces, and even modern threats like guns and knives (Blanchette, 2006; Brosch & Sharma, 2005; LoBue & DeLoache, 2008; LoBue, 2009, 2010; Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001). Experiment 2 was designed to examine the role of cognition in detection, and more specifically, whether using a threatening label ("snake") leads to more rapid detection than using a nonthreatening label ("caterpillar"). Although there was no significant main effect of label, there was a marginal label by target interaction, suggesting that when a threatening label is paired with a perceptually appropriate stimulus like a curvilinear shape, detection is facilitated slightly more than when using the threatening label or curvilinear shape alone. It is possible that the manipulation was too weak to elicit a main effect or to facilitate detection above and beyond baseline; in other words, simply labeling a stimulus as a "snake" did not fully bring to mind a snake's threatening properties for all participants. Future investigations could make the threatening features more explicit (e.g., "Some snakes have deadly venom,") in order to examine whether a stronger manipulation would lead to larger differences in detection. This work has theoretical implications for threat detection, suggesting that cognitive features alone may not drive rapid threat detection, but they might facilitate detection of stimuli that already have other threat-relevant features. It also has methodological implications, as in many detection paradigms, the targets are labeled (e.g., LoBue & DeLoache, 2008), although in others, they are not (e.g., Öhman, Lundqvist, & Esteves, 2001). Future research is needed to fully establish how cognitive factors might change or heightened detection findings across paradigms.

Finally, Experiment 3 examined the role of emotional state in detection. The results demonstrate that when primed with an emotion-eliciting (fearful) video, participants were faster to detect all targets than when primed with a neutral video, suggesting that an emotional state facilitates detection. Further, the target by emotion interaction shows that when participants are induced with an emotional video and then asked to detect a curvilinear shape, detection is even faster than when the video or perceptual cue are presented alone. Based on these data, we can conclude that an emotional induction facilitates detection. Because a fearful video was compared with a neutral or nonemotion eliciting video, we cannot conclude that fear per se drove the results, only that an emotionally arousing video more generally leads to faster detection. Future research can compare a fearful induction with other emotional inductions (e.g., exciting, angry, sad, disgusting, etc.) to explore whether eliciting different emotions produces differential responding in a threat detection task.

Together, these results suggest that rapid threat detection in adults cannot necessarily be attributed to one single factor—perceptual, cognitive, and emotional factors can each play a role in rapid threat detection. It is possible that each factor can function on its own to produce rapid detection, and that a combination of cues might lead to even more efficient search. In fact, when considering only conditions in which adults detected curvilinear lines, participants were slowest when curvilinear line was presented alone, they were slightly faster when a curvilinear line was presented with a threatening label, and participants were fastest when a curvilinear line was presented with an emotional induction. Thus, the current work suggests that threat detection is the result of several factors in which low-level perceptual features of threatening stimuli, knowledge about the nature of threat, and our emotional response to these stimuli all play individual and interacting roles in detection.

Although these results are important for understanding how we come to be sensitive to threats in our environment, they are perhaps not surprising. In adulthood, experience and knowledge about threat is likely to play a role in the conscious processing and detection of threatening stimuli. The most important question for future research is *when* in development do each of these cues becomes important for threat detection? As mentioned above, perceptual sensitivity to threats like snakes and spiders might have developmental origins. Preschool children quickly detect stimuli like snakes and spiders and threatening facial expressions (LoBue, 2009, 2010; LoBue & DeLoache, 2008). Even 8- to 14-month-old infants turn more quickly to look at snakes and angry faces than at flowers and happy faces (LoBue & DeLoache, 2010), and 5-month-olds are more attentive to spider-like configurations than configurations that resemble flowers (Rakison & Derringer, 2008). Thus, it is possible that low-level perceptual biases for threat begin early in life, and cognitive and emotional cues become important later in development. We are currently in the process of examining this important developmental question.

Another important question for future research is whether perceptual, cognitive, and emotional cues play a role in the detection of other threats besides snakes. As mentioned above, there are other threats that share a snake's curvilinear features—spiders, for example, have curved bodies and legs. In fact, Rakison and Derringer (2008) report that as early as 5 months of age, humans have a perceptual template for curvilinear spider-like configurations. However, not all threats have curvilinear features, and indeed not all curvilinear stimuli are threatening. Thus, future work is needed to examine other threats, such as angry or threatening facial expressions, and how perceptual, cognitive, and emotional cues might interact to drive their detection.

Similarly, future research should examine other properties of threats that might contribute to their rapid detection. It is possible,

for example, that certain types of biological motion, such as a snake's slithering, might also facilitate detection. In a natural environment, such as a walk in the woods, anomalous movement might be an important cue for threat detection. Indeed, a snake's movement has been implicated in previous work as an important perceptual cue in driving how humans might quickly associate snakes with fear (DeLoache & LoBue, 2009). A similar question is how perceptual, cognitive, and emotional features function in the natural environment to facilitate threat detection. Future research can elucidate what other factors might function to facilitate rapid threat detection, and how the features identified here might function to facilitate detection in a more natural environment.

One final point to note is that in the experiments presented here, participants were required to make physical contact with the target stimuli by touching them on the screen. It is logical to assume that requiring participants to make physical contact with photographs of threatening stimuli might actually slow responding instead of facilitating it. Thus, the results presented here might be interpreted the opposite way, and suggest that it is *rectilinear* lines that are a diagnostic for threat, and impair approach-related responses. Indeed, previous research has suggested that adults have a preference for curvilinear over rectilinear shapes (Bar & Neta, 2006, 2007). However, we do not believe this to be the case for two reasons. First, extensive work using the touch-screen paradigm has shown consistently that threatening stimuli, including snakes, spiders, and angry faces, are detected (and touched on the screen) more quickly than a variety of neutral stimuli, including frogs, caterpillars, cockroaches, happy, and neutral faces by both adult and child participants (e.g., LoBue, 2009, 2010; LoBue & DeLoache, 2008, 2011). This is consistent with a larger literature showing the same pattern of responding using other behavioral measures that do not require participants to make physical contact with stimuli. In fact, a recent study directly compared the standard button-press detection paradigm used by Ohman, Flykt, and Esteves (2001) and countless other studies to the touch-screen paradigm used here within the same adult participants. The results showed that participants produce the same pattern of responding across the two tasks, and despite the fact that only the touch-screen task requires participants to make physical contact with the images, both paradigms produce the same advantage for threat (LoBue & Matthews, 2014).

Second, several studies in the social psychology literature suggest that the pressing motion required for the touch-screen detection paradigm is more in line with an *avoidance* response than an *approach* response. More specifically, Caccioppo and colleagues have proposed that the act of pulling toward oneself, or arm flexion, is associated with approaching positive stimuli, and the act of pushing, or arm extension, produces feedback in the body that is akin to avoiding negative stimuli. Several studies support this view (for a review, see Friedman & Forster, 2000). For example, participants who were asked to rate neutral stimuli during an arm flexion task preferred the stimuli more than participants who rated them during an arm extension task (Caccioppo, Priester, & Berntson, 1993). Similarly, participants are quicker to respond to positively valenced stimuli when they have to pull a lever toward them than when they have to push a lever away, and respond more quickly to negative stimuli when they have to push a lever away than when they have to pull a level toward them (Chen & Bargh, 1999). In the case of the touch-screen paradigm presented here, although participants are required to make physical contact with

each stimulus, in doing so, they are required to produce a pushing motion, which is generally associated with avoidance of negative stimuli. This idea is completely consistent with the current findings and with findings from previous work, demonstrating that participants are faster to respond to threatening stimuli in both the touch-screen and in other paradigms.

In conclusion, this work is one of the first examinations of the mechanisms by which human adults rapidly detect threat. Together, the findings suggest that threat detection is not the result of a single factor, but instead, can result from the individual and interacting roles of perceptual, cognitive, and emotional factors.

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