Original Article

# Venom, speed, and caution: effects on performance in a visual search task

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Initial receipt 30 May 2011; final revision received 15 November 2011

## Abstract

Previous reports of faster responses to threatening compared to benign stimuli in visual search tasks have argued that threatening targets are faster to engage and slower to disengage attention than benign targets. This study reinterprets previous findings and resolves inconsistencies in the literature by replacing the theory of differential disengagement of attention with one of differential caution. It also examines whether visual attentional mechanisms are sensitive to more than just the threatening versus benign categorical status of the targets and introduces a novel measure (a caution score) that appears to be sensitive to the level of threat implied by the target image, but immune to other stimulus features (target-distracter similarity and threat status of distracters) known to affect reaction time. As well as locating threatening targets faster than benign targets, participants were also faster, more accurate, and more cautious to detect lethal spiders compared to nonlethal spiders and even more cautious again if the spiders were presented on a person's hand. These results suggest that mechanisms of attention and threat evaluation interact during visual search tasks, producing behaviour that is sensitive to the target's implied threat level and the context in which that target is presented.
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*Keywords:* Visual search tasks; Threat detection; Attention; Caution

## 1. Introduction

Visual search tasks have been used extensively to assess how ecologically relevant stimuli capture attention, revealing faster and sometimes more accurate identification of threatening stimuli, such as angry faces (using both photographs, Gerritsen, Frischen, Blake, Smilek, & Eastwood, 2008; Hansen & Hansen 1988; and schematics, Fox et al., 2000; Öhman, Lundqvist, & Esteves, 2001) and snakes and spiders (first demonstrated by Öhman, Flykt, & Esteves, 2001, and subsequently affirmed by others, including Blanchette 2006; Brosch & Sharma 2005; Flykt 2005; and Fox, Griggs, & Mouchlianitis, 2007), when compared to nonthreatening stimuli. Both children (LoBue & DeLoache 2008) and prelingual infants (LoBue & DeLoache 2010) respond to snakes more rapidly than flowers, suggesting that an initial perceptual bias is present early in development and may be independent of experience or explicit knowledge of danger. LoBue (2010) has also demonstrated, however, that in children recent aversive experience with potentially dangerous man-made objects (syringes) is associated with those objects being located faster. Taken together, these findings suggest that preexisting biases interact with experiences that induce fear to shape the mechanisms responsible for biasing attention toward potentially threatening objects.

Typically, these tasks use images from the benign target category as distracters for the threatening targets and vice versa (Brosch & Sharma 2005; Öhman, Flykt, et al., 2001). For the threatening targets, a target-present trial would present one image of the threatening target amongst several images of the benign distracter, while a target-absent trial would only present images of the benign distracters. For the nonthreatening targets, this arrangement would be reversed with the threatening images now being presented as the distracters. Participants are typically required to respond by declaring all items to be the 'same' (meaning the target is absent) or that one item is 'different' (meaning the target is present; Fig. 1 presents two versions of this typical paradigm and the modified paradigm of the present study). Although successful in identifying differences in response times

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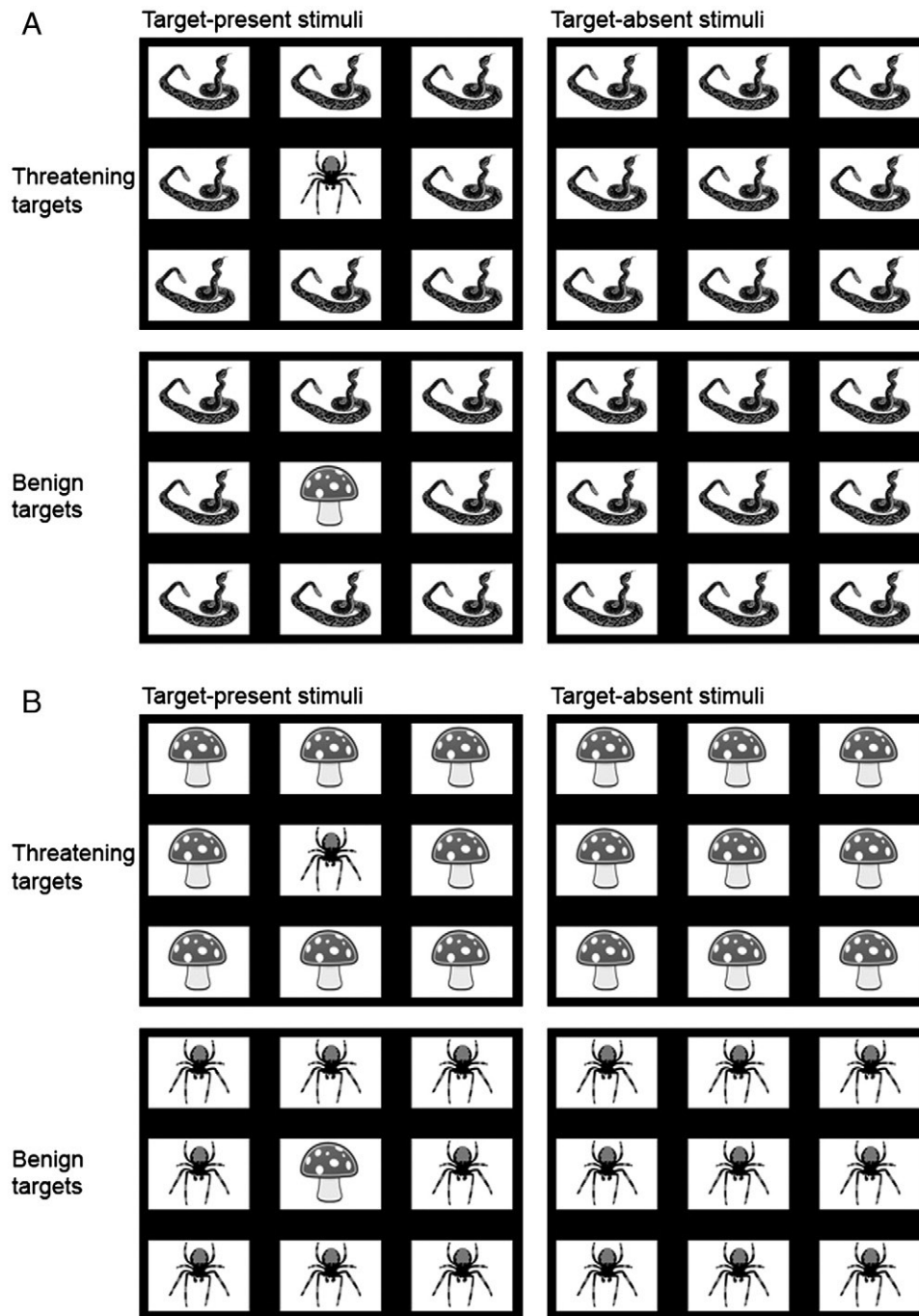*E-mail address:* danielle.sulikowski@ymail.com.

Fig. 1. The crucial differences in design between Flykt (2005) and Brosch and Sharma (2005). (A) Flykt presented both threatening and benign targets surrounded by threatening and benign distracters. (B) Brosch and Sharma presented threatening targets with benign distracters only and vice versa. (C) The design of the present study presented trials blocked by target and used distracters from a variety of different nontarget categories. NB: In all studies, colour photographs were used with multiple exemplars from each category. Black and white pictures with only one exemplar from each category are used here simply for visual clarity.

between threatening and benign stimuli, this method has the major drawback of confounding target and distracter identity, making it difficult to determine whether it is the targets that are identified more quickly or the distracters that are rejected more quickly that is responsible for the observed effects. Flykt (2005; see Fig. 1a) embedded benign and threatening targets, respectively, within both benign and threatening distracters. The results suggested that threatening stimuli capture attention more quickly, accounting for faster reaction times when the target is threatening, and may take longer to disengage attention, accounting for slower reaction times when threatening distracters surround a benign target.
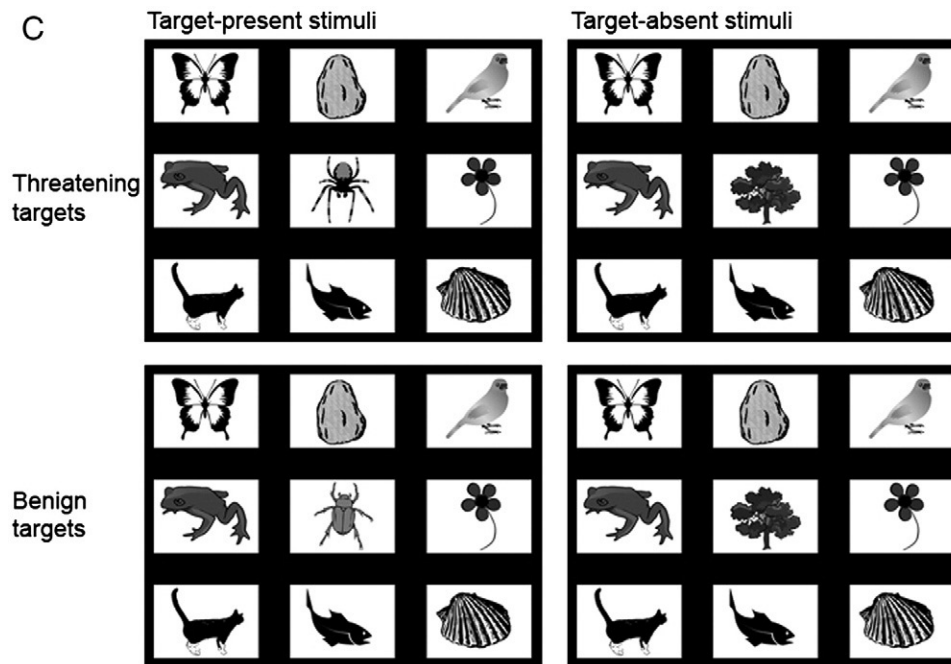
Fig. 1. (*continued*).

At this stage, I will differentiate between two supposed effects mentioned above that threatening targets have on visual attention. The first is that threatening stimuli capture attention more quickly than nonthreatening stimuli. The second is that threatening stimuli disengage from attention more slowly (hold it for longer) than nonthreatening stimuli. While there is good evidence from other paradigms that threatening stimuli can take longer to disengage attention than benign stimuli (Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004, for example), I will argue that this second process does not adequately explain the data from visual search tasks and offer an alternative explanation that parsimoniously accounts for apparent inconsistencies in the literature. The inconsistencies I refer to concern participant behaviour in target-absent trials of visual search tasks. Brosch & Sharma (2005; see Fig. 1b), for example, found that participants were slower to declare that all stimuli were the same if the stimuli were threatening than if they were benign on target-absent trials. Flykt (2005), however, found the exact opposite effect in his target-absent trials. If time to engage and time to disengage attention were the drivers of reaction times in target-absent trials, both studies should have found the pattern reported by Brosch & Sharma (2005). One possibility is that response time in the target-absent trials of the above studies was not driven by slow disengagement of attention from threatening distracters, but that participants were adaptively trading off the benefits of responding quickly with the relatively increased costs of potentially missing a threatening versus a benign target whenever possible. The design of the current study (Fig. 1c) tested this possibility by combining the logic of

signal detection theory with Weber's Law to derive a measure of participant caution.

Signal detection theory (Green & Swets, 1974) uses hit-rate (correctly identifying a target as present) and false-alarm rate (incorrectly identifying a target as present when it is absent) to calculate receiver criterion. A high criterion means that a receiver will have few false alarms, but many misses (failing to identify a target that is present). This would translate to not being very cautious in layman's terms, only detecting really obvious signals (in our case, threats), but missing potentially less obvious ones. A low criterion will miss few targets but commit more false alarms. This would translate to being quite cautious—almost all threats will be detected and even some nonthreatening stimuli may be misinterpreted as threatening, 'just-in-case'. The criterion an individual adopts is influenced by the relative costs of misses and false alarms. For example, signal detection theory would predict that a doctor attempting to diagnose a life-threatening disease would adopt a lower criterion (check every lump carefully, even the ones that are probably benign) to a doctor attempting to diagnose dietary deficiencies (don't screen everybody, just those patients showing likely symptoms). If traditional signal-detection theory were applied directly to these visual search paradigms, it would predict that if the target is threatening such that missing it would be costly, people would act more cautiously and adopt a lower criterion to avoid misses, at the cost of extra false alarms. This is not an appropriate paradigm, however, in which to test such predictions about accuracy of responding (there are simply not sufficient false alarms, responding that a target is present when it is not, to calculate criterion level). Instead, the same

underlying logic has been applied in order to use reaction time data (from both target-present and target-absent trials) to derive an alternative measure of criterion, a caution score, to estimate the relative costs the participants attach to missing the threatening versus benign targets. The logic of the caution score is based on the notion that responses on target-absent trials do not occur because participants have screened each distracter in turn and decided the target is not there. Rather, responses occur because a certain amount of time has passed and the target has not been detected.

Two features of the current study that have not typically been present in previous studies—presenting the trials associated with different target types in separate blocks (rather than intermingling the target types) and using identical distracter sets for threatening versus benign targets—were critical to deriving and validating the caution score measure. By blocking the trials by target type, on any given trial, participants knew both the target they were searching for and how long on average it had taken them to locate this target during previous target-present trials of that block. Responses on target-absent trials, therefore (when participants have been instructed to respond as quickly as possible), may reflect the fact that as the average target-present response time lapses on a target-absent trial, it becomes less likely that the target is present, and the participants become more likely to terminate their search and decide that the target is absent. Since the distracter stimuli presented on target-absent trials of the threatening and benign targets are identical in the current study, a difference in reaction time to these trials, mirroring the difference seen in target-present trials, would strongly suggest that such a timing mechanism is terminating the search in target-absent trials. No difference in reaction times between the threatening and benign conditions on target-absent trials, on the other hand, would suggest that search is simply terminated when all distracter items have been inspected and dismissed (since such differences were evident in the data, the simple notion of serial search can be ruled out).

This proposed timing mechanism is reminiscent to a similar 'timing threshold' proposed by Wolfe & Cave (1989) as the primary mechanism responsible for terminating search on target-absent trials in their Guided Search model. In a later version of this model (Chun & Wolfe 1996), the timing mechanism was relegated to a secondary (but still necessary) role in determining the response time to target-absent trials, with the primary determinant deemed to be the absence or presence of specific combinations of visual features (colour, orientation of lines, etc.). The current paradigm, however, uses a unique exemplar as the target in each trial and the relatively complicated nature of the stimuli (coloured photographs) precludes participants from being able to identify targets, or rule out distracters, based on the presence or absence of such basic visual features. This, then, leaves the hypothesised timing mechanism as the most likely determinant of reaction time in target-absent trials of the current study (Chun & Wolfe 1996; Wolfe & Cave 1989).

Now, if participants are engaging a timing mechanism to decide when to terminate their search on target-absent trials, how much longer than the average target-present reaction time should participants wait before deciding the target is indeed absent? Based on the above scenario, Weber's Law (which states that the just-noticeable difference between two stimuli will be directly proportional to the magnitude of the stimuli) predicts that the absolute magnitude of the increase in reaction time from target-present to target-absent trials should be proportional to the mean reaction times of the target-present trials (Grondin, 2001). Therefore, as a general null hypothesis, if participants are equally cautious in response to all targets, but are engaging a timing mechanism to terminate search on target-absent trials, the increase in reaction time from target-present to target-absent trials should be of the same proportion for all targets. On the other hand, if participants are behaving more cautiously when searching for particular targets, a greater proportionate increase in reaction time from the target-present to target-absent trials and therefore a higher caution score are predicted. Thus, the joint determinants of response time on target-absent trials for any given condition are hypothesised to be mean response time on target-present trials and level of threat implied by the target. The caution scores, as a measure of the proportionate increase in reaction time from target-present to target-absent trials, are independent of absolute reaction times (in the same way that measures of contrast are independent of measures of absolute luminance) and so ought to be immune from the effects of stimulus factors (such as target-distracter similarity, distinctiveness of target, etc.) known to influence response times on visual search tasks.

Differential levels of participant caution may explain the conflicting findings on target-absent trials between the studies of Brosch and Sharma (2005) and Flykt (2005). The critical difference in methodology between these two studies (illustrated in Fig. 1a and b) is that participants in Brosch and Sharma's paradigm could predict the category of the target (benign or threatening) from the category of the distracters (threatening or benign). If these participants were applying Weber's Law as described above to determine response times on target-absent trials, one would predict longer response times to target-absent trials with threatening stimuli because, when these displays contain a target, it is benign and so takes longer to locate. However, the relative increase in reaction time from target-present to target-absent trials should be greater for benign distracters (which only ever contain threatening targets) as participants take extra time to ensure that the threatening target is indeed absent. Although not discussed in this way by the authors, this is exactly the pattern of data reported in Brosch & Sharma (2005). In Flykt's study on the other hand, distracter category was not a reliable predictor of target category, and so relative caution toward potentially missing a target was the same for all target-absent arrays, leaving only differential attentional engagement to explain the results. In

Table 1
Categories of targets and distracters

| Condition | Target | Distracters |
| --- | --- | --- |
| 1. Beetles | Various species of beetles | Multiple categories of natural objects[a] |
| 2. Lethal spiders | Species of spiders whose bites are potentially lethal to humans | Multiple categories of natural objects[a] |
| 3. Caterpillars | Various species of caterpillars | Multiple categories of natural objects[a] |
| 4. Snakes | Species of poisonous snakes | Multiple categories of natural objects[a] |
| 5. Snakes w/ spiders | Species of poisonous snakes | Various species of spiders |
| 6. Safe spiders | Nondeadly spiders | Multiple categories of natural objects[a] |
| 7. Hand-spiders | Lethal spiders pictured on a person's hand | Multiple categories of natural objects all pictured on/in a person's hand[b] |
| 8. Hand-beetles | Beetles pictured on a person's hand | Multiple categories of natural objects all pictured on/in a person's hand[b] |

[a] The natural categories from which these distracter items were drawn were cats, flowers, trees, goldfish, frogs, rocks, butterflies, shells, and birds.

[b] The natural categories from which these distracter items were drawn were cats, plants, soil rocks, birds, frogs, flowers, butterflies, and hands on their own.

this study, participants were faster to decide that arrays containing all threatening (versus all benign) stimuli were the same. Thus, differential attentional engagement and caution can collectively account for all previous findings, without recourse to the notion of differential disengagement of attention. The current study tests this reinterpretation by surrounding threatening targets (in this case, snakes) by both threatening and benign distracters, respectively, in a design wherein participants know whether they are searching for threatening or benign targets. The level of caution participant's display ought not to be affected by whether the distracters are benign or threatening, whilst absolute response times on target-present trials are predicted to increase when threatening distracters are used.

Using this novel measure of participant caution, the present study investigated whether threat-sensitive mechanisms of attentional capture respond to more than just the basic stimulus category (of 'spider' for example). Participants' performance when they were searching for species of spiders whose bites are potentially lethal was compared with their performance when searching for spiders whose bites do not kill humans. Spider targets were also presented crawling across a person's hand to determine whether the level of threat implied by the context of the target object affects attentional capture (all target and distracter stimuli are summarised in Table 1). Consistent with the theory that perceptual/attentional mechanisms preferentially allocate resources to processing threatening stimuli when presented against a background of heterogeneous benign distracters, evolutionarily significant threats (snakes and spiders) would be located faster, more accurately, and more cautiously than nonthreatening control targets (caterpillars and beetles). Spiders whose bites are potentially lethal would be located faster, more accurately, and more cautiously than spiders whose bites are not lethal. Lastly, if the mechanisms responsible for threat assessment are sensitive to context, spiders whose bites are potentially lethal will be located with more caution amongst benign distracters if they are presented in a context that indicates a more immediate threat (pictured crawling across a person's hand) compared to a less immediate threat (pictured on a plant or on the ground).

## 2. Methods

### 2.1. Participants

Forty-eight participants (33 female) aged from 18 to 50 ($M$=23.81, S.D.=6.39) volunteered, and all gave informed consent. During the testing session, participants completed a series of visual search tasks in addition to those reported in the current paper. All tasks were completed in counter-balanced order over the 48 participants.

### 2.2. Design

The experiment contained eight conditions, determined by the category of the target for which participants were instructed to search and/or the category of the distracters. The 18 trials for each condition (nine target-present and nine target-absent trials) were blocked and presented in random order within each block. All participants completed all eight blocks. Half of the participants (counterbalanced) completed Conditions 1, 2, 3, and 4 (in random order) before Conditions 5, 6, 7, and 8 (also in random order) with condition numbers as designated in Table 1.

### 2.3. Stimuli

Colour photographs, which presented target and distracter objects against natural backgrounds, were used as stimuli. The particular images used as targets and distracters differed from trial to trial so that each array presented to participants contained unfamiliar and dissimilar images. This method both increased the ecological validity of the task relative to previous studies and, following the recommendations of Öhman, Flykt, and Lundqvist (1999), made it extremely unlikely that chance selection of stimuli with unusual characteristics would create spurious results. The photos were sourced primarily from the internet. Copyright laws allow use of such images for research purposes only, but not for publication; therefore, Fig. 2 contains images taken only by the author and is included to illustrate the nature of the stimuli and the way the arrays were presented, but does not represent the particular collection of images actually presented in any given trial. All stimulus images were converted, using Adobe Photoshop v11.0.2 for Mac, to

A                                                                 B
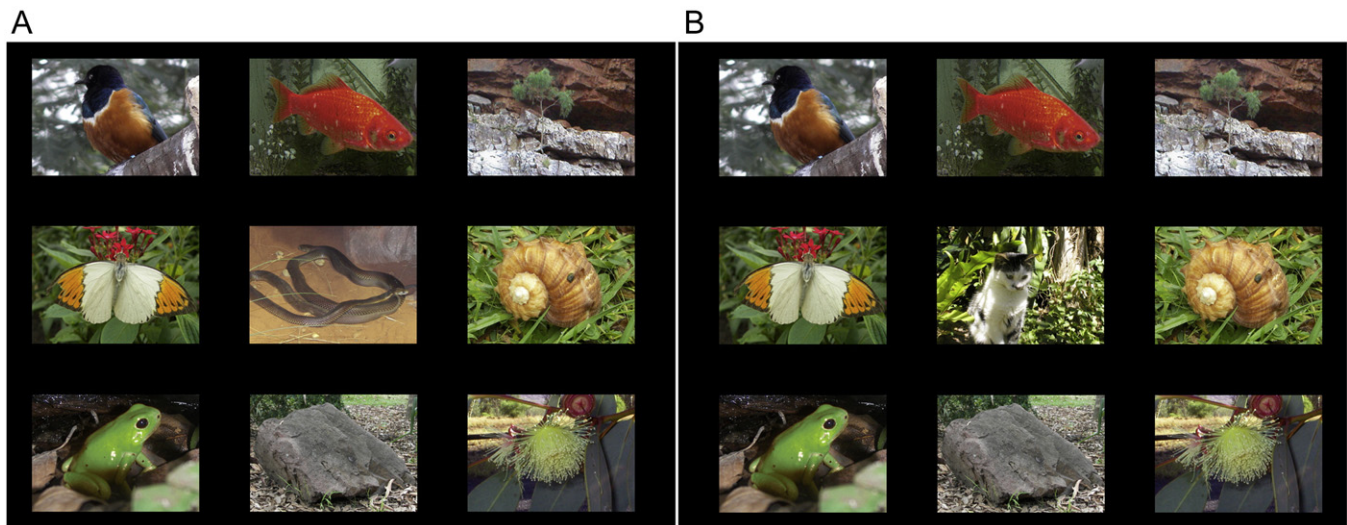


Fig. 2. Illustrative examples of a (A) target-present and (B) corresponding target-absent array. In this example, the snake is the target. The arrays used for the corresponding target-present and target-absent trials for the caterpillar targets (the nonthreatening control targets paired with the snakes) were identical to those shown here except that the picture of the snake in the target-present array would be replaced with a picture of a caterpillar.

rectangles of 198×283 pixels at a resolution of 72 ppi and presented during the experiment in full RGB colour against a black background.

### 2.3.1. Target stimuli

The target stimuli for the eight conditions of this experiment came from seven different categories: beetles, caterpillars, snakes (used in two conditions), safe spiders, lethal spiders (defined as species of spiders whose bites are potentially lethal to humans), lethal spiders pictured crawling across a person's hand (hand-spiders), and beetles pictured crawling across a person's hand (hand-beetles). Each target category was used in one condition, except for the snakes category. These stimuli were used in two conditions, each time surrounded by a different set of distracters (described below). There were nine target images from each category, each presented in only a single trial (for each target category, there were nine target-present and nine target-absent trials). For these nine trials, the target images appeared in each of the nine possible locations (stimuli were always presented in a 3×3 grid) exactly once.

The types of spiders in the safe spiders category included species common in Australia such as crab spiders (Thomisidae) and common orb weavers (*Eriophora* spp.) that do not inflict potentially lethal bites. Spiders in the lethal spiders categories (spiders and hand-spiders) included species such as funnel webs (*Hadronyche* or *Atrax* spp.), redbacks (*Latrodectus hasselti*), and mouse spiders (*Missulina* spp.) that can inflict lethal bites. Following LoBue and DeLoache (2008), beetles and caterpillars were chosen to be the corresponding 'safe' comparison categories for the spiders and snakes, respectively, due to similarity between the body shapes of these creatures. It was also important to choose animals as the corresponding safe targets (previous studies have tended to use flowers or mushrooms) as the results of

Tipples, Young, Quinlan, Broks, and Ellis (2002) have suggested that even nonthreatening animals may be found faster than plants and as fast as threatening animals in visual search tasks.

### 2.3.2. Distracter stimuli

The lethal spiders, safe spiders, beetles, snakes, and caterpillars conditions presented these targets against distracters from nine categories: cats, flowers, trees, goldfish, frogs, rocks, butterflies, shells, and birds. A total of 81 distracter images (nine different images from each of the nine categories) were used for the 18 trials in each condition. Each target-absent trial was made up of one image from each of the nine distracter conditions, with each corresponding target-present trial including the same images, but with one of them replaced by a target. Thus, each distracter image appeared in only one target-absent trial and one target-present trial (if it wasn't the image replaced by the target). For those conditions across which direct comparisons were planned (beetles, safe spiders & lethal spiders, and caterpillars & snakes), the exact same distracter images were used such that the target-absent trials (and target-present trials, except for the actual target) of these conditions presented identical stimuli. This was done to keep the level of familiarity that participants would gain with the various distracter images similar across all conditions of the study. Using different distracter images for conditions where direct comparisons are not planned (lethal spiders versus snakes, for example) does mean that differences in reaction time or accuracy between these conditions cannot be confidently attributed to the target; however, no predictions are made about such comparisons, and their outcomes are of no theoretical consequence within the scope of the current study.

For the hand-spiders and hand-beetles conditions, where the targets were presented in pictures either on or in a person's

hand, the distracters were similarly presented in pictures of hands and came from the following nine categories: cats, plants, soil, rocks, birds, frogs, flowers, butterflies, and hands on their own. Similar to above, a total of 81 of these distracter images (nine from each category) were used, with each distracter image appearing only twice in each condition, once each in a target-absent trial and a corresponding target-present trial (unless it was replaced by the target). Again, as comparisons were planned between these two conditions, the same distracter images were used such that the stimuli presented in target-absent and target-present (except for the actual target) trials of these conditions are identical.

As mentioned above, the snake targets were presented across two conditions: with distracters from multiple categories as described above and also in a snakes-with-spiders condition, where the snake targets were always surrounded by images of potentially lethal species of spiders (none of the images used as targets in the lethal spiders conditions were used as distracters in this condition). Across the 18 trials of this condition, 81 different distracter images were used, each image appearing in only one target-absent and one target-present trial (unless it was replaced by the target).

### 2.4. Procedure

Participants completed the experiment on a 17-in. iMac computer. The stimuli were delivered by Superlab v4.0.3c for Mac. The ethical aspects of the study were approved by the Macquarie University Human Research Ethics Committee (Ref. no. HE27FEB2009-RO6284L&P).

As a condition of ethics approval, participants were initially shown some hard-copy photographs of spiders and snakes and asked whether they were comfortable completing an experiment in which they would be required to view and search for these objects. Participants were asked not to participate if they had any phobias or anxieties related to the stimuli, or were for any reason uncomfortable with the stimuli. This screening process did not rule out any potential participants.

Instructions on the screen informed participants that they were to press either the 'absent' key or the 'present' key, depending upon whether an image from a prespecified target category was absent or present. On a standard keyboard, the s-key and k-key were labelled 'absent' and 'present' (respectively, for half the participants, reversed for the other half). Participants were additionally instructed to place each of their index fingers on the 'absent' and 'present' labelled keys before they began so that they could respond as quickly as possible.

Onscreen instructions informed participants whether they were searching for 'spiders' (the safe spiders, lethal spiders, and hand-spiders conditions), 'beetles' (the beetles and hand-beetles conditions), 'caterpillars', or 'snakes' (the snakes and snakes with spiders conditions). Each trial began with a fixation cross (500 ms), followed by the search array (which remained on the screen until participants responded). Immediately following the participant's response, the next trial began, and no feedback was given. At the end of each condition, instructions for the following condition appeared on the screen until all eight conditions were completed.

Accuracy and reaction time (RT) were recorded for analysis, and a third dependent variable, the caution score, was calculated from the reaction time data as follows;

$$\frac{\left(RT_{absent} - RT_{present}\right)}{\left(RT_{absent} + RT_{present}\right)},$$

where $RT_{absent}$ refers to the mean RT from the target-absent trials (of the condition in question) and $RT_{present}$ refers to the mean RT from the corresponding target-present trials. This formula creates a normalised score that is directly proportionate to the relative difference between the mean RT of the target-absent and target-present trials for each condition.

### 3. Results

Analyses were conducted using PASW v18.0 for Mac. All analyses and comparisons were planned a priori (unless otherwise indicated), and alpha levels were fixed at 0.05. Analyses were conducted on the accuracy data (from the target-present trials only), the RT data (from correct responses to the target-present and target-absent trials), and

Table 2
Summary of planned analyses

| Hypothesis | Relevant conditions | Relevant subsection |
|---|---|---|
| Threatening targets will be found more accurately, more quickly, and more cautiously than nonthreatening targets. | Repeated-measures ANOVAs directly compared the beetles to the lethal spiders, the caterpillars to the snakes, and the hand-beetles to the hand-spiders. | 3.1 |
| Increasing the level of threat implied by both the identity and context of the target image will tend to increase accuracy, reaction time, and expressed caution. | Repeated-measures ANOVAs compared responses to the following conditions (in order of increasing level of implied threat): beetles, safe spiders, lethal spiders, hand-spiders. | 3.2 |
| Presenting threatening targets amidst threatening distracters will tend to reduce speed and accuracy of responding but will have no affect on expressed caution (when compared to using benign distracters). | Paired-samples *t* tests compared responses to the snake condition (where benign distracters were used) to the snake w/ spiders condition (where the distracters were all spiders). | 3.3 |

the caution score data. Table 2 presents a summary of these analyses.

### 3.1. Comparisons between dangerous and safe targets

General linear model (GLM) repeated-measures analyses of variance (ANOVAs) with threat (two levels: dangerous, safe) and matched pair (three levels: lethal spider/beetle, snake/caterpillar, hand-beetle/hand-spider) as within-subjects factors and sex as a between-subjects factor revealed that, as predicted, the dangerous targets were located faster, more accurately, and more cautiously than the safe targets.

### 3.1.1. Accuracy

As predicted, dangerous targets were found significantly more accurately than safe targets ($F_{1,46}=25.617$, $p<.001$, $\eta^2_\rho=0.358$). Paired-samples $t$ tests (Bonferroni corrected alpha of 0.017 applied) confirmed that this difference was significant for the lethal spider/beetle pair ($t_{47}=6.255$, $p<.001$, Cohen's $d=1.21$), marginal for the hand-spider/-hand-beetle pair ($t_{47}=2.398$, $p=.021$, Cohen's $d=0.33$), and not significant for the snake/caterpillar pair ($t_{47}=1.243$, $p=.220$, Cohen's $d=0.20$). There was no main effect of matched pair and so no overall difference in accuracy between the three matched pairs of targets ($F_{2,92}=0.783$, $p=.460$, $\eta^2_\rho=0.017$). There was, however, a significant interaction between matched-pair and sex ($F_{2,92}=5.042$, $p=.008$, $\eta^2_\rho=0.099$), with females finding all three dangerous targets more accurately than their corresponding safe targets, whereas males located the lethal spiders and hand-spiders more accurately than the beetles and hand-beetles, respectively, but not so for the snakes versus the caterpillars (Fig. 3). Although sex was included as a factor in all analyses, it did not figure in any other significant effects
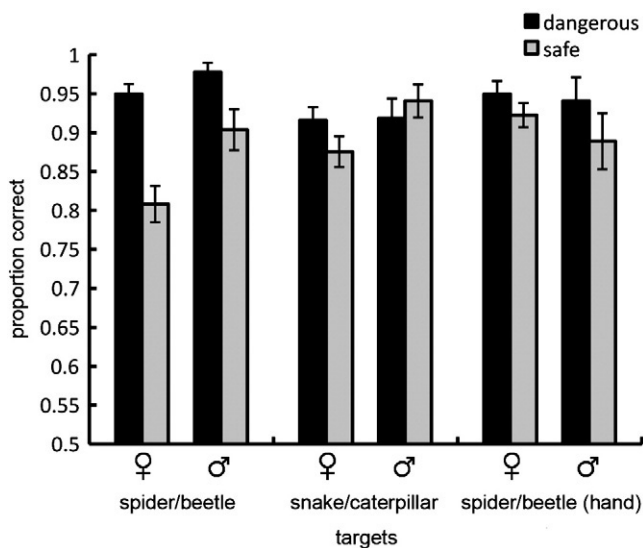


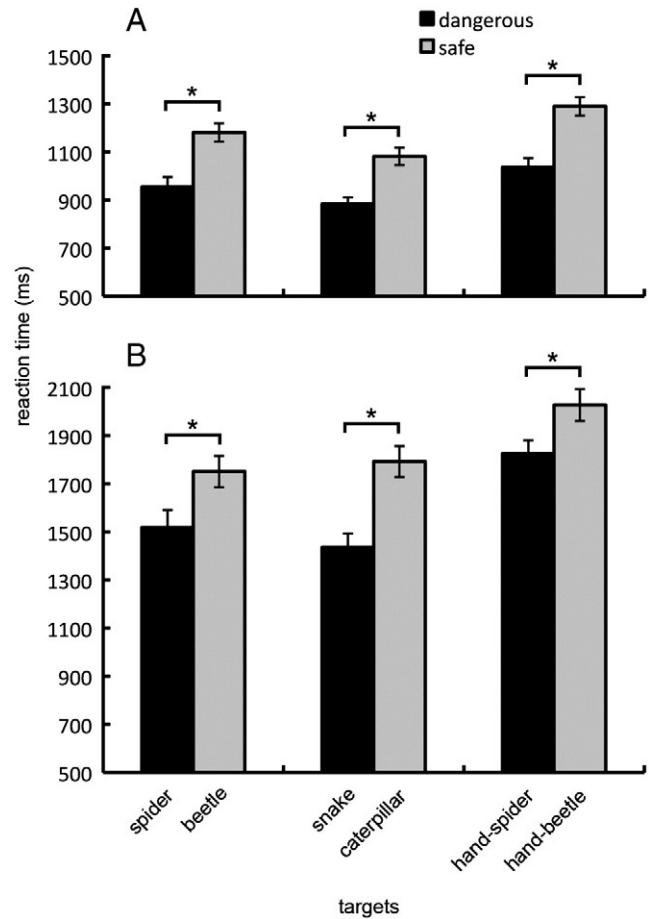Fig. 4. The mean reaction times (±1 S.E.) for the (A) target-present trials and (B) target-absent trials for the three matched pairs of targets. *Statistically significant difference.

or interactions and so will not be mentioned further in the Results section.

### 3.1.2. Reaction time

Within the target-present trials, as predicted, the dangerous targets were found significantly faster than safe targets ($F_{1,46}=130.6$, $p<.001$, $\eta^2_\rho=0.740$, see Fig. 4a). Paired-samples $t$ tests (Bonferroni corrected alpha of 0.017 applied) confirmed this difference as significant for all three matched pairs (all $t_{47}>7.2$, all $p<.001$, all Cohen's $d>0.81$). There was also a significant main effect of matched pair ($F_{2,92}=17.140$, $p<.001$, $\eta^2_\rho=0.271$), with the snake/caterpillar pair being found the fastest and the hand-spider/-hand-beetle pair being found the slowest. Post hoc simple contrasts (Bonferroni corrected alpha of 0.017 applied) confirmed that the participants took significantly longer to locate the target in the hand-spider/hand-beetle pair than the lethal spider/beetle pair ($F_{1,46}=7.601$, $p=.008$, $\eta^2_\rho=0.142$) and the snake/caterpillar pair ($F_{1,46}=40.840$, $p<.001$, $\eta^2_\rho=0.470$). Responses were also faster to the snake/caterpillar pair compared to the spider/beetle pair ($F_{1,46}=8.440$, $p=.006$, $\eta^2_\rho=0.155$).



Fig. 3. The mean (±1 S.E.) proportion of target-present trials in which participants correctly identified the target as present for the three matched pairs of targets.
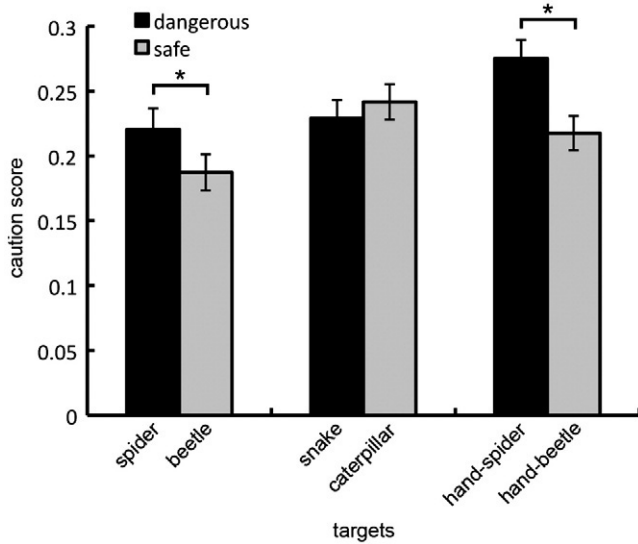
Fig. 5. The mean caution scores (calculated as the difference between the mean reaction times for the target-present and target-absent trials divided by the sum of these means, ±1 S.E.). *Significant difference.

Within the target-absent trials, participants were significantly faster to decide that dangerous targets were absent than that safe targets were absent ($F_{1,46}=64.369$, $p<.001$, $\eta^2_\rho=0.583$, see Fig. 4b). Paired-samples $t$ tests (Bonferroni corrected alpha of 0.017 applied) confirmed this difference as significant for all three matched pairs (all $t_{47}>3.5$, all $p<.002$, all Cohen's $d>0.48$). There was also a significant main effect of matched pair ($F_{2,92}=26.536$, $p<.001$, $\eta^2_\rho=0.366$). Post hoc simple contrasts (Bonferroni corrected alpha of 0.017 applied) confirmed that participants took longer to decide that the target was absent for the hand-beetles/hand-spiders pair compared to the lethal spider/beetle

pair ($F_{1,46}=26.697$, $p<.001$, $\eta^2_\rho=0.367$) and compared to the snake/caterpillar pair ($F_{1,46}=43.583$, $p<.001$, $\eta^2_\rho=0.487$).

### 3.1.3. Caution score

As predicted, participants behaved significantly more cautiously in response to the dangerous versus the safe targets ($F_{1,46}=5.027$, $p=.030$, $\eta^2_\rho=0.099$, see Fig. 5). There was also, however, a significant interaction between target status and matched pair ($F_{2,92}=4.251$, $p=.017$, $\eta^2_\rho=0.085$), and post hoc paired-samples $t$ tests (Bonferroni corrected alpha of 0.017 applied) revealed that participants responded significantly more cautiously to the dangerous target in the lethal spider/beetle pair ($t_{47}=2.489$, $p=.016$, Cohen's $d=0.32$) and the hand-spider/hand-beetle pair ($t_{47}=3.550$, $p=.001$, Cohen's $d=0.61$), but not in the snake/caterpillar pair ($t_{47}=0.810$, $p=.422$, Cohen's $d=0.13$).

There was also a significant main effect of matched pair ($F_{2,92}=4.966$, $p=.009$, $\eta^2_\rho=0.097$), with post hoc simple contrasts (Bonferroni corrected alpha of 0.017 applied) revealing that participants responded significantly more cautiously to the hand-spider/hand-beetle pair than to the lethal spider/beetle pair ($F_{1,46}=8.079$, $p=.007$, $\eta^2_\rho=0.149$), with no differences between the snake/caterpillar pair and either of the other two pairs (hand-spider/hand-beetle: $F_{1,46}=1.662$, $p=.204$, $\eta^2_\rho=0.035$; lethal spider/beetle: $F_{1,46}=3.748$, $p=.059$, $\eta^2_\rho=0.075$).

### 3.2. Effects of increasing the levels of threat of spider targets

GLM repeated-measures ANOVAs with threat (three levels: safe spider, spider, hand-spider) as the within-subjects variable and sex as a between-subjects variable revealed that, consistent with predictions, lethal spiders were located faster and more accurately than safe spiders and
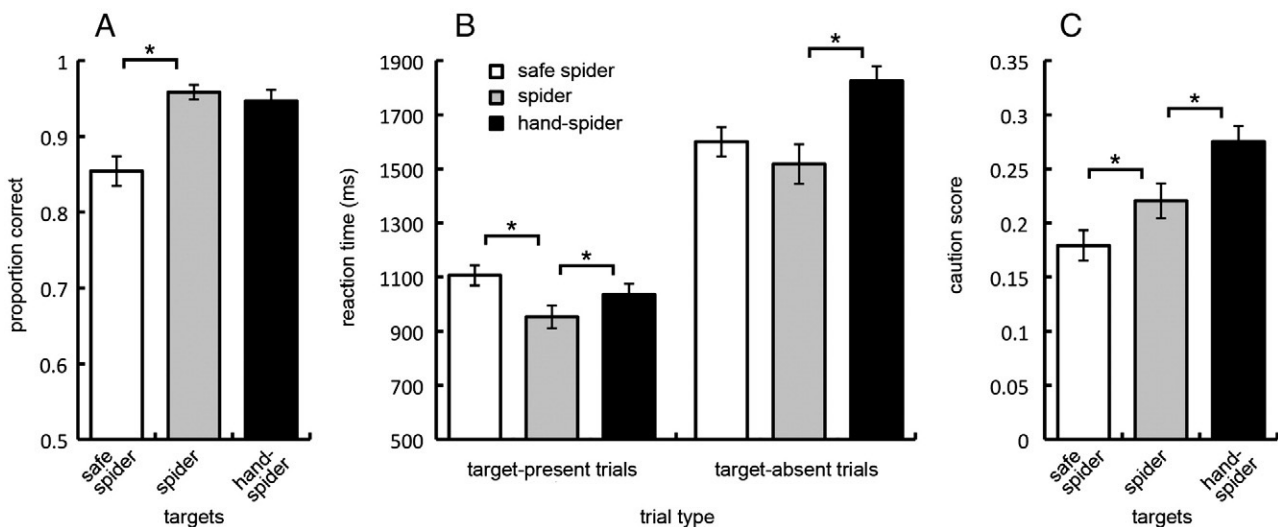


Fig. 6. The (A) mean (±1 S.E.) proportion of target-present trials on which participants correctly identified that the target was present; (B) mean (±1 S.E.) reaction times for the target-present and target-absent trials; and (C) the mean (±1 S.E.) caution scores for the 'safe-spiders', 'spiders', and 'hand-spiders' targets. *Significant difference.
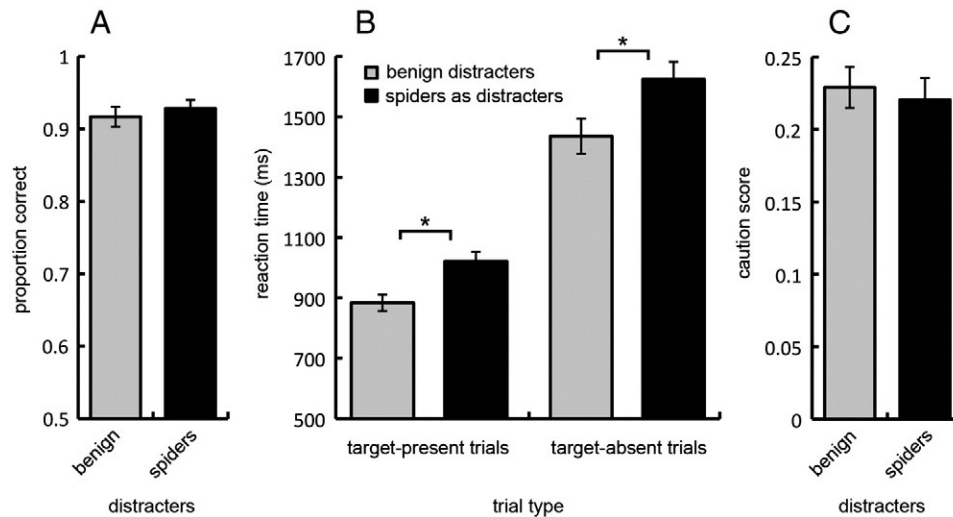
Fig. 7. The (A) mean (±1 S.E.) proportion of target-present trials on which participants correctly identified that the target was present; (B) mean (±1 S.E.) reaction times for the target-present and target-absent trials; and (C) the mean (±1 S.E.) caution scores for the 'snake' targets when they were surrounded by heterogeneous benign distracters compared to when they were surrounded by 'spiders' as distracters.

caution levels increased as the target and its context increased the level of threat posed.

#### 3.2.1. Accuracy

There was a significant main effect of threat ($F_{2,92}=11.844$, $p<.001$, $\eta^2_\rho=0.205$, see Fig. 6a). Paired-samples $t$ tests (Bonferroni corrected alpha of 0.025 applied) revealed a significant increase in accuracy from the safe spiders to the lethal spiders ($t_{47}=5.148$, $p<.001$, Cohen's $d=1.03$) and then no further increase from the lethal spiders to the hand-spiders ($t_{47}=0.636$, $p=.528$, Cohen's $d=0.14$).

#### 3.2.2. Reaction time

Considering the target-present trials, there was a significant main effect of threat level ($F_{2,92}=8.740$, $p<.001$, $\eta^2_\rho=0.160$, Fig. 6b). Paired-samples $t$ tests (Bonferroni corrected alpha of 0.025 applied) revealed a significant decrease in reaction time from the safe spiders to the lethal spiders ($t_{47}=3.562$, $p=.001$, Cohen's $d=0.56$) and a significant increase in reaction time from the lethal spiders to the hand-spiders ($t_{47}=2.413$, $p=.020$, Cohen's $d=0.30$).

Considering the target-absent trials, there was a significant main effect of threat level ($F_{2,92}=10.912$, $p<.001$, $\eta^2_\rho=0.192$, see Fig. 6b). Paired-samples $t$ tests (Bonferroni corrected alpha of 0.025 applied) revealed no difference between the lethal spiders and safe spiders ($t_{47}=1.346$, $p=.185$, Cohen's $d=0.19$) and a significant increase in reaction time from the lethal spiders to the hand-spiders ($t_{47}=4.205$, $p<.001$, Cohen's $d=0.69$).

#### 3.2.3. Caution score

There was a significant main effect of threat level ($F_{2,92}=15.221$, $p<.001$, $\eta^2_\rho=0.249$, see Fig. 6c). Consistent with predictions, paired-samples $t$ tests (Bonferroni corrected alpha of 0.025 applied) revealed participants responded significantly more cautiously to the hand-spiders than the

lethal spiders ($t_{47}=2.880$, $p=.006$, Cohen's $d=0.52$) and significantly more cautiously to the lethal spiders than the safe spiders ($t_{47}=2.351$, $p=.023$, Cohen's $d=0.39$).

### 3.3. Effects of threatening versus benign distracters

Consistent with the hypothesis that threatening stimuli, in this case, distracters, capture attention, participants found the snake targets significantly more quickly (paired-samples $t$ test, $t_{47}=5.578$, $p<.001$, Cohen's $d=0.68$), though not more accurately (paired-samples $t$ test, $t_{47}=0.726$, $p=.472$, Cohen's $d=0.13$), when they were surrounded by benign rather than threatening distracters. Participants were also significantly faster (paired-samples $t$ test, $t_{47}=3.612$, $p=.001$, Cohen's $d=0.47$) to decide the snake targets were absent when benign distracters were used. Consistent with the caution measure being independent of factors not related to the threat level of the target itself (but which may influence reaction time on target-present trials), there was no effect of benign or threatening distracters on the level of caution measured (paired-samples $t$ test, $t_{47}=0.544$, $p=.589$, Cohen's $d=0.08$, see Fig. 7), which was remarkably similar across these two conditions.

## 4. Discussion

Consistent with the hypothesis that the perceptual/attentional mechanisms underlying visual search performance are adapted to recognise and promote quick processing of imminent threats, participants in this study were faster to respond to the threatening targets (snakes and spiders) than they were to respond to the benign targets (caterpillars and beetles). There was also evidence that the relevant mechanisms were sensitive to more than just the broad categorisation of the targets, with lethally poisonous species

of spiders found more quickly than nonlethal species of spiders. Furthermore, the caution score applied by comparing the relative increases in reaction time from the target-present to target-absent trials for each target supported the hypothesis that participants would wait longer to avoid responding incorrectly to a target-absent trial when the potential target presented a greater threat. This was true whether the greater threat was indicated by broad categorical judgments (for example, spider or beetle), more fine-grained categorical judgements (lethal spider or nonlethal spider), or the context in which the threat presented itself (a lethal spider either crawling across a hand or pictured on a plant or on the ground). Participants responded equally cautiously to snake targets whether they were surrounded by benign or threatening distracters, even though the snake targets took longer to locate when surrounded by threatening distracters, supporting the reinterpretation of previous studies.

### 4.1. Comparisons between dangerous and safe targets

The direct comparisons between spiders and beetles and between snakes and caterpillars reaffirmed previously reported findings (Brosch & Sharma, 2005; Flykt, 2005; LoBue & DeLoache, 2008; Öhman, Flykt, et al., 2001) that threatening targets are found faster than safe targets. Tipples et al. (2002) and Lipp, Derakshan, Waters, and Logies (2004) have both suggested that all animals (irrespective of the threat level they pose) are equally preferentially located (versus nonanimal stimuli) in visual search tasks. Such a conclusion would cast doubt over the veracity of many of the previous findings (including Öhman, Flykt, et al., 2001) as they used nonanimal benign targets (such as flowers and mushrooms) for comparison. The current data do not support this conclusion and suggest that not all animal stimuli are of equal salience and/or relevance. Rather, consistent with the findings of LoBue and DeLoache, (2008), potentially dangerous animals were located faster and more accurately than their similarly shaped, nonthreatening counterparts.

### 4.2. Effects of increasing the levels of threat posed by dangerous targets

While several previous studies have established preferential processing of spider stimuli when compared to flowers or mushrooms (and beetles, in the current study), no previous reports exist demonstrating that the relevant mechanisms are sensitive to more than just the broad categorical designation of 'spider' (or snake, or predator). Faster and more cautious responding to the more poisonous species of spiders in this study suggests that it is not merely the cognitive categorisation of the stimulus as a spider that results in differential allocation of attention. Rather, these findings suggest that the combination of physical features that highly venomous spiders share and/or the potential underlying knowledge of the toxicity of various species directs attention. Toxic and noxious species that share common predators often evolve convergent morphological forms, a phenomenon known as

Müllerian mimicry (Turner, 1987). The common morphological features signal toxicity to potential predators, who can evolve and/or learn sensitivities to these signals and then avoid preying upon all similar morphological forms (Ham, Ihalainen, Lindström, & Mappes, 2006). Rowe and Guilford (1996) have demonstrated that particular combinations of signals presented together, which are not aversive when presented separately, can trigger innate avoidance tendencies in predators. The combination of morphological traits shared by the most lethal species of spiders (hairier bodies, shorter legs, and larger abdomens) may combine to produce a warning signal of toxicity to which humans are sensitive. An alternative interpretation of the current data is that participants knew which species were poisonous and which ones were not and this explicit knowledge produced the effect. A necessary test of these hypotheses would be to train people that various species are poisonous or not poisonous (irrespective of their actual toxicity) and see whether this explicit knowledge affects the outcome more or less than the actual toxicity of the spiders involved.

There are also no previous reports of evidence that the level of threat implied by the context in which the target is pictured can affect performance in a visual search task. Whilst participants took longer in absolute terms to locate the lethal spiders when they were presented on hands versus when they were not, the caution measure revealed the predicted effects of increased threat on participant behaviour. Since high similarity of distracters to targets increases target response times in visual search tasks (Duncan & Humphries, 1989), the presence of hands in both target and distracter images in the hand-spiders condition would be expected to increase reaction time relative to the nonhand condition. Whether the size of this increase would be smaller or larger than any potential decrease in reaction time due to increased threat would have been impossible to ascertain a priori. The caution score, however, allowed direct comparisons of behaviour between these two conditions and revealed that participants were indeed sensitive to the increased level of threat implied by the presentation of the lethal target on a person's hand compared to when the target was merely presented in the external environment. Thus, proximity to self may be a cue that moderates the urgency of the response to perceived visual threats. There is some evidence from patient studies that visual attention is directed preferentially toward stimuli that are close to the subject's hand (di Pellegrino & Frassinetti, 2000). In macaque ventral premotor cortex, there are neurons that respond to tactile stimuli on the arm as well as visual stimuli presented close to the arm (Graziano, Hu, & Gross, 1997), while activity of neurons in the frontal eye field is modulated by the position of the hand relative to a target object (Thura, Hadj-Bouziane, Meunier, & Boussaoud, 2010), emphasising the importance of processing objects in peripersonal space. Further investigations would be needed to determine the relationship, if any, between the mechanisms that process objects in peripersonal space and the findings of the present study.

## 4.3. Effects of threatening versus benign distracters

Flykt (2005) demonstrated that threatening targets take longer to locate when surrounded by threatening (versus benign) distracters. This finding was replicated in the current study, with participants taking longer to locate the snake targets when surrounded by spiders compared to benign distracters. Although Flykt (2005) interpreted this finding as indicating that it takes longer to disengage attention from threatening versus benign stimuli, this finding can also be explained just by faster engagement of attention by threatening stimuli. If attentional resources are finite and are equally likely to be directed toward the threatening distracters as the threatening target in a visual search, this will result in longer reaction times to locate the target than a scenario in which attentional resources are directed preferentially toward the target and away from benign distracters.

With respect to target-absent trials, however, the current findings were not consistent with those reported by Flykt (2005), as participants in the current study took longer to decide that the snake targets were absent when presented with threatening distracters. This was also the pattern reported by Brosch and Sharma (2005). Although discussed by those authors as consistent with attention taking longer to disengage from threatening targets, this finding is more precisely accounted for by participants applying Weber's Law to the timing of responses in target-present trials to determine reaction time in target-absent trials. Two outcomes from the current study are critical for the validity of this explanation. The first is that participants were equally cautious of deciding a snake target was absent whether it was surrounded by threatening or benign distracters, irrespective of the fact that using threatening distracters increased overall reaction times. The second is that the reaction time effects reported for target-present trials (faster detection of more threatening targets) were mirrored in the target-absent trials of the present study. An explanation that appeals to differential disengagement from threatening versus benign distracters would predict no differences in reaction time on the target-absent trials of the present study, as distracter stimuli were identical in the target-absent trials of threatening and nonthreatening conditions. Thus, an explanation for differences in reaction time on target-absent trials in these types of studies must include some reference to the relationship between responding on target-present and target-absent trials, as reaction time to target-absent trials is not merely a proximate response to the stimuli presented. In the present study, this relationship has been presented as a caution score, which was highly related to the level of threat implied by the target stimulus, but not related to the level of threat implied by distracter stimuli.

## 4.4. Future directions

Findings from the present study suggest several avenues of future investigation. Firstly, manipulations of images of spiders need to be done along with quantitative comparisons of morphology between lethal and nonlethal species of spiders to determine whether a convergent morphological signal of toxicity has evolved to which humans are sensitive receivers. Secondly, manipulations of knowledge people have about the toxicity associated with particular images of spiders will reveal the extent to which such declarative knowledge affects responding in these types of tasks.

The third avenue of future investigation relates to snakes as targets in these types of studies. While there is strong evidence that snakes are reliably located more quickly when compared to nonanimal benign targets (such as mushrooms, Flykt, 2005; Öhman, Flykt, et al., 2001) and that children (LoBue & DeLoache, 2008) and prelingual infants (LoBue & DeLoache, 2010) attend more quickly to snakes than other benign targets, comparisons between snakes and other similarly shaped animals have not yielded results quite as robust. While no studies have reported participants responding significantly more slowly to snakes than to a similar benign target, LoBue & DeLoache (2008) failed to find a significant difference in reaction time to snakes compared to caterpillars in an adult sample. In the present study, although snakes were found more quickly than caterpillars, males failed to find them more accurately, and there was no difference in caution score for the snakes compared to the caterpillar targets. There are several reasons why behavioural responses to snakes may not be more urgent or cautious than responses to caterpillars. One possibility is that whatever the features are that direct our attention toward snakes (be it the reptilian head or elongated body) may not figure prominently in every picture of a snake. Furthermore, if the elongated (and sometimes curled-around) body shape of a snake is critical for detection and these features are exhibited in pictures of caterpillars, then the caterpillar stimuli may activate some of the snake-relevant mechanisms. Thus, the particular images one chooses may impact on whether participants respond differently to snakes and caterpillars. Future studies may seek to systematically vary the images used to determine the necessary and sufficient morphological features of snakes that result in increased urgency and cautious responding.

## 4.5. Conclusions

The current study provides evidence that mechanisms of engaging visual attention are sensitive to aspects of stimuli that signal varying levels of threat. Participants were faster and more accurate in detecting threatening targets (snakes, spiders) than benign comparison targets (caterpillars and beetles), and their responses differentiated between potentially lethal and nonlethal species of spiders and between spiders that were and weren't presented within peripersonal space. Comparisons between reaction times in target-present and target-absent trials, via the newly derived caution score, suggest that participants' behaviour was sensitive to the differential costs of failing to detect threatening versus benign targets. These findings suggest

that selection pressures to avoid the bites of lethally toxic species have produced perceptual mechanisms that interact with mechanisms of threat evaluation in order to rapidly detect the visual signals of such species and direct attention preferentially toward those signals. These data reaffirm the relevance of taking an evolutionary perspective when investigating the way attentional mechanisms are engaged by functionally relevant stimuli. They also highlight the importance of merging theory and evidence from the fields of cognitive science and evolutionary biology in order to understand the origin and function of human psychological mechanisms.

## Acknowledgments

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