Threat Captures Attention but Does Not Affect Learning of Contextual Regularities

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Abstract

Some of the stimulus features that guide visual attention are abstract properties of objects such as potential threat to one's survival, whereas others are complex configurations such as visual contexts that are learned through past experiences. The present study investigated the two functions that guide visual attention, threat detection and learning of contextual regularities, in visual search. Search arrays contained images of threat and non-threat objects, and their locations were fixed on some trials but random on other trials. Although they were irrelevant to the visual search task, threat objects facilitated attention capture and impaired attention disengagement. Search time improved for fixed configurations better than for random configurations, reflecting learning of visual contexts. Nevertheless, threat detection had little influence on learning of the contextual regularities. The results suggest that factors guiding visual attention are different from factors that influence learning to guide visual attention.

Keywords: Threat detection; visual search; contextual learning; attention capture; attention capture; implicit learning.

Efficient deployment of visual attention to the locations or objects of interest is important in everyday activities. The present study focuses on two mechanisms that facilitate visual search, (a) detection of objects that pose threat to one's survival and (b) learning of the contextual regularity in the environment. From an evolutionary perspective, quick detection of threat objects is of utmost importance to increase the chance of survival (Öhman, Flykt, & Esteves, 2001), whereas taking advantage of the regularities in the environment helps to avoid aversive events or support foraging of commodities to satisfy one's needs. The present study addresses the issue of how these two mechanisms may (or may not) interact to aid an efficient search of visual scenes.

Threat Advantage to Guide Visual Attention

Certain objects in the environment are correlated with danger, so they need to be reacted to quickly to avoid aversive consequences (Öhman et al., 2001). Researchers suggest that the visual system sets priority for processing such objects by default, allowing rapid detection of threat-related stimuli in an automatic fashion. A number of studies demonstrated that threat stimuli facilitate attention capture and impair attention disengagement (Yiend, 2010). One of the prominent methods to demonstrate these phenomena has been a visual search paradigm. In a visual search task, participants are presented with an array of visual objects and search it for a target. Search time is shorter when the target is a threat object than when it is a non-threat object, reflecting a *facilitated attention capture*. Search time is longer when distractors are threat objects than when they are non-threat objects, reflecting an *impaired attention disengagement*. Studies also found that search time for a threat target was not affected by the number of non-threat distractors, implying that detection of a threat target among neutral distractors is preattentive or automatic (Hensen & Hensen, 1988; but see, Fox et al., 2008). Studies have

demonstrated this threat advantage for detection when threat values of stimuli are task-relevant (Hensen & Hensen, 1988) or -irrelevant (Hodsoll, Viding, & Lavie, 2011). Threat advantage has been suggested to have an evolutionary basis and thus depend on an innate faculty (Öhman, Flykt, & Lundqvist, 1999), but humans can also be conditioned to associate threat with novel stimuli to produce a similar threat advantage for the conditioned stimuli (Koster et al., 2005). Therefore, learning is also a contributing factor for the threat advantage for detection.

Learning Contextual Regularities to Guide Visual Attention

Visual attention can also be guided by prior experiences with the regularities of visual contexts (Chun & Jiang, 1998). This is important as taking advantage of contextual regularities would help avoiding life-threatening events when these regularities are associated with threat objects. A previous study suggests that people learn to deploy attention to spaces in which threat is more likely to appear (Notebaert, Crombez, Van Damme, De Houwer, & Theeuwes, 2010). Instead of focusing on the predictability of threat at particular locations, the present study focuses on whether the presence of threat would affect learning of contextual regularities to guide attention to the target location. For this purpose, we used the *contextual cuing paradigm* (Chun & Jiang, 1998), in which half of the visual arrays are repeated over trials (*fixed contexts*) whereas the other half are constructed randomly on each trial (*random contexts*). Visual search becomes more efficient for fixed contexts than for random contexts over time, implying that the observers learn the regularities and take advantage of them when guiding visual attention. Learned contexts have been shown to be implicit as participants are unable to recognize or recall them above the chance level (Chun & Jiang, 2003).

Although learned contexts are implicit memory, there are mixed results as to whether contextual learning is implicit or requires attention (see Goujon, Didierjean, & Thorpe, 2015, for

a review). The contextual cuing effect increases as the number of distractor items increases

(Chun & Jiang, 1998), suggesting that a longer inspection time on the contexts facilitates

learning. A study also found that the contextual cuing effect decreased as a salient singleton

distractor disrupted attention to the context (Conci & von Mühlenen, 2009), but the effect

increased as the similarity between targets and distractors increased (Conci & von Mühlenen,

2011), the factor that is known to determine the efficiency of visual search (Duncan &

Humphreys, 1989). However, another study found no influence of target-distractor similarity

(Rausei, Makovski, & Jiang, 2007). The contextual cuing effect also depends on selective

attention, as the effect emerges based only on the regularities in an attended set of objects, not

those in an ignored set (Conci & von Mühlenen, 2011; Jiang & Chun, 2001). However, the

contextual cuing effect is reinstated immediately based on the regularities in the ignored set

when participants switch their attention to the ignored set (Jiang & Leung, 2005), suggesting that

the expression of the learned context, not learning itself, requires attention. Some studies also

showed a smaller contextual cuing effect under high working memory load (Travis, Mattingley,

& Dux, 2013) while others showed little influence of memory load (Vickery, Sussman, & Jiang,

2010). Hence, whether contextual learning requires attention is still an unresolved issue.

The Present Study

Threat detection and learning of contextual regularities are two important functions to

guide visual attention. They are also important for increasing the chance of survival. From this

view, it is reasonable to assume that contextual learning would become more efficient when the

regularities help locating threat objects as it would enable one to avoid future encounters to these

objects (Notebeart et al., 2010). Therefore, the present study investigated the influence of threat

detection on learning of contextual regularities in visual scenes and examined whether attention

is required for contextual learning. The experiment involved visual search in which search

arrays consisted of coloured Landolt squares that contained photographic images of threat-

related (spiders) and -unrelated (mushrooms) objects (see Figure 1). The target was defined by

the colour and the orientation of the Landolt square, so the images within squares were irrelevant

to the task. For half of the trials, the target and distractor positions were fixed at the beginning of

a session and presented repeatedly; for the other half, they were determined randomly on each

trial (Chun & Jiang, 1998). Three aspects of the present procedure deserve particular emphases.

First, threat/non-threat images were irrelevant to the visual search task and participants

were encouraged to ignore the images as much as possible. Previous studies demonstrated threat

advantage when threat values were relevant to visual search (Koster et al., 2005; Hansen &

Hansen, 1988; Öhman et al., 2001), and others demonstrated threat advantage when threat values

were irrelevant (Notebaert et al., 2011; Hodsoll et al., 2011). The latter studies used the

additional singleton paradigm with social stimuli (facial expressions) or stimuli conditioned to

induce fear. They showed that an irrelevant fear-relevant singleton enhanced target detection

when it appeared at the location of the target, but slows target detection when it appeared at the

location of a distractor.   These results indicate that a task-irrelevant singleton can facilitate

attention capture and impair attention disengagement. The present study further assessed the

influences of threat stimuli on attention capture and disengagement while using non-social,

naturally occurring stimuli (spiders/mushrooms) in a visual search paradigm. It is of interest to

examine whether threat detection would facilitate attention capture (shorter search time when the

target contains a threat object than when it contains a non-threat object) or attention

disengagement (longer search time when distractors contain threat objects than when they

contain non-threat objects). Second, in fixed contexts, the irrelevant images that appeared at the

locations of target and distractors were the same, but the identities of the target and distractors (colour and orientation) were selected randomly on each trial. This differed from previous studies in which the contextual regularities were maintained in terms of the target and distractor identities (e.g., Chun & Jiang, 1998). Thus, the present experiment allowed testing whether the regularities in irrelevant contexts would be learned to guide attention. Last, the study addressed the issue of whether factors guiding visual attention also influence learning to guide visual attention (Jiang & Leung2005; Conci & von Mühlenen, 2011). If threat stimuli attract visual attention, the context may be inspected more thoroughly when distractors contain threat stimuli, making contextual learning more efficient; the visual context may not be inspected sufficiently when the target contains a threat stimulus, making contextual learning less efficient. Therefore, threat stimuli would influence contextual learning if factors guiding visual attention also affects learning to guide visual attention.

Method

Participants

Twenty eight undergraduate students at Edge Hill University volunteered for the present experiment (18 females; mean age 20.39, range 20-22). From previously published studies with similar designs, the current sample size was determined to be sufficient to detect effects under consideration. All participants reported having normal or corrected-to-normal visual acuity and normal colour vision.

Apparatus and Stimuli

The apparatus consisted of a personal computer and a 19-in flat screen monitor. A search array consisted of a 4 x 4 invisible grid that contained ten Landolt squares (5 cm x 5 cm) with a 1-cm gap on one of the sides (see Figure 1A); there was 0.5 cm space between two adjacent

squares. One square was the target and nine were distractors. The square frames were coloured in green, red, yellow, or blue, presented against a white background, and they had a gap on either side. The target was a square in a pre-specified colour with the gap on the left or right. The target colour was determined randomly for each participant. Each Landolt square contained a threat or non-threat photographic image (see Figure 1B). There were four types of search arrays: (1) both target and distractor squares contained images of spiders; (2) both target and distractor squares contained images of mushrooms; (3) the target contained an image of a spider, and the distractors contained images of mushrooms; and (4) the target contained an image of a mushroom, and the distractors contained images of spiders. Responses were registered by pressing the left ("z") or right ("/") key on a QWERTY keyboard with the left and right index fingers, respectively, according to the orientation of the target Landolt square.

Procedure

The experiment was conducted individually in a cubicle. Participants sat in front of the computer monitor at an unrestricted viewing distance of 50 cm and read on-screen instructions. Participants were informed of the colour of the target square at the beginning of the experiment. They were also told that the images in squares were irrelevant to the task, so they should ignore the images as much as possible.

Each participant performed 12 practice trials, followed by a total of 576 test trials, which were divided into 6 blocks of 96 trials each. Participants were allowed to take a short rest after each block. A test block was composed of 4 sub-blocks of 24 trials each, which was unknown to participants. For twelve trials (*fixed context*), the computer generated the target and the distractor positions at the beginning of the session. Note that the images within the target and the distractors were also fixed throughout the session; however, the colours and orientations of the

distractor squares were generated randomly on each trial, so was the orientation of the target.

For the remaining twelve trials (*random context*), the target and distractor positions were

generated randomly at the beginning of each trial. The original study of this paradigm (Chun &

Jiang, 1998) preselected target locations for random contexts. Thus, participants could have

learned repeated target locations (Zellin, von Mühlenen, Müller, & Conci, 2013) and attended

selectively to a subset of possible target locations when the context is unfamiliar to them. The

present design excluded this form of learning with random contexts. In each of the context

conditions, the four display types occurred three times each.

Each trial started with a fixation cross at the centre of screen for 1000 ms, which was

replaced by a search array that was presented until a response or for 2000 ms if no response was

made. The feedback message "Good!" was given for correct responses and "Error!" for

incorrect or no responses, which lasted for 750 ms. The overall response accuracy was shown on

the display every six trials; participants were instructed to keep the accuracy at 90% or above.

Search time was defined as the interval between the onset of a visual array and a keypress. A

session took less than an hour.

Results

The data from two participants were excluded due to low overall accuracy (> 40% error

rate). Trials for which no response was made within 2000 ms or RT was less than 200 ms were

discarded (1.86% of all trials). Mean search time for correct trials and percentages of error trials

were computed for each participant and submitted to a 6 (Block: 1-6) x 2 (Context: fixed vs.

random) x 2 (Target Type: threat vs. non-threat) x 2 (Distractor Type: threat vs. non-threat)

repeated-measures analysis of variance, with all factors being within-subject variables. When

the sphericity assumption was violated, the Greenhouse-Geisser correction was used to adjust p-

values (but the original degrees of freedom were reported). As no significant effect emerged for percentage errors, we focused on search time only.

Threat Advantage for Visual Attention

The threat advantage can take two forms, facilitated attention capture and impaired disengagement. Facilitated attention capture is implied when the target that contains a threat image is detected faster than the target that contains a non-threat image, which corresponds to the main effect of Target Type. Impaired attention disengagement is implied when the target is detected faster with distractors containing non-threat images than with distractors containing threat images, which corresponds to the main effect of Distractor Type. Both effects were significant; Target Type, $F(1, 24) = 20.23$, $MSE = 38,957.61$, $p < .001$, $\eta_p^2 = .447$, and Distractor Type, $F(1, 24) = 15.99$, $MSE = 45,179.00$, $p < .001$, $\eta_p^2 = .390$. Search time was shorter for threat target ($M = 927$ ms) than for non-threat target ($M = 977$ ms), whereas it was shorter for non-threat distractor ($M = 928$ ms) than for threat distractor ($M = 976$ ms). These two factors did not interact, $F(1, 24) < 1$ (see Figure 2A). The effects on attention capture (50-ms facilitation) and disengagement (48-ms impairment) were similar in magnitude.

Contextual Learning for Visual Attention

The contextual cuing effect is indicated when visual search becomes more efficient for fixed contexts than for random contexts over blocks, which corresponds to the interaction between Block and Context. This effect was significant, $F(5, 120) = 2.33$, $MSE = 7,908.60$, $p = .046$, $\eta_p^2 = .085$. For fixed contexts, there was a 99-ms reduction from the first block ($M = 996$ ms) to the final block ($M = 897$ ms). For random contexts, there was a 45-ms reduction from the first block ($M = 990$ ms) to the final block ($M = 945$ ms). In other words, the difference in search time between the fixed and random contexts (i.e., the context effect) was – 6 ms in the

first block and increased to 48 ms in the final block, demonstrating that visual search became

more efficient with fixed contexts than with random contexts over blocks. Thus the results

revealed the contextual cuing effect. In general, search time decreased over blocks; main effect

of Block, $F(5, 120) = 10.18$, $MSE = 22,192.30$, $p < .001$, $\eta_p^2 = .289$.

Influence of Threat Advantage for Contextual Learning

Given that both the effects of threat advantage and of contextual learning were obtained,

their interaction is of interest. If contextual learning depends on attention, learning would be

more efficient for non-threat targets than for threat targets as shorter time is allowed to inspect

the visual context when the threat targets capture attention; this corresponds to the three-way

interaction among Block, Context, and Target Type. Similarly, contextual learning would be

more efficient for threat distractors than for non-threat distractors as longer time is allowed to

inspect the visual context when the threat distractors impair disengagement; this corresponds to

the three-way interaction among Block, Context, and Distractor Type. Neither of these

interactions were significant, Fs < 1.3, ps $> .2$. Figure 2B shows a plot of the contextual learning

effect for the four display types against block and fitted least-squared regression lines. A steeper

slope of the regression line indicates more efficient contextual learning. From visual inspection,

the slopes appeared to be steeper for threat distractors than for non-threat distractors, but this

impression is not supported statistically due to the lack of significant interactions. Hence, the

present results are consistent with the idea that learning of contextual regularities does not

require attention.

Influence of Target-Distractor Similarity on Contextual Learning?

In addition to the aforementioned results, there was a significant main effect of Context,

$F(1, 24) = 6.25$, $MSE = 22,054.84$, $p = .019$, $\eta_p^2 = .200$, and a significant interaction among

Context, Target Type, and Distractor Type, $F(1, 24) = 7.69$, $MSE = 16,650.73$, $p = .010$, η_p^2 $= .235$. Search time was shorter with fixed contexts ($M = 939$ ms) than with random contexts ($M = 965$ ms), and this advantage for the fixed contexts was larger when the target and distractors contained images from the same category (homogeneous display; 46 ms) than when they contained images from different categories (heterogeneous display; 5 ms), consistent with a previous study that suggested the influence of target-distractor similarity on the contextual cuing effect (Conci & von Mühlenen, 2011). However, the interpretation requires caution. The contextual cuing effect can emerge quickly after a brief exposure to repeated contexts (Goujon et al., 2015), so it is possible that these context effects resulted from contextual learning. Yet, there was no effect of target-distractor similarity, and it is also possible that search times differed between these conditions by chance because search arrays were constructed randomly. Therefore, the contextual cuing effect would be inferred more unambiguously from the changes of the context effect over blocks; this corresponds to the interaction among all four variables. The interaction was not significant, $F(5, 120) = 1.95$, $p = .091$. Thus, the present study does not provide strong evidence that contextual learning depends on the target-distractor similarity.

Discussion

Visual attention is guided by the environmental features as well as by top-down control that weighs processing of visual information according to their pertinence. These features are not limited to the primitive visual properties of objects, but certain complex sets of features can also affect the operation of visual attention. The present study focused on two factors that guide visual attention, threat detection and contextual cuing. Three aspects of the present study are particularly important.

First, the threat advantage was obtained when threat stimuli were irrelevant to search the target. Previous studies have already shown that an irrelevant singleton in the search display slows target detection when the singleton carries negative valence (Notebaert et al., 2011; Hodsoll et al., 2011). The present results reinforce these findings by showing that threat stimuli facilitate attention capture and impair attention disengagement even when they are irrelevant in visual search. Although the effect on attention disengagement has been shown to be more robust than that on attention capture when threat values are task-relevant (Yiend, 2010), the effects on capture and disengagement were similar in the present experiment. Note also that the studies using the additional singleton paradigm have used social or conditioned stimuli to induce negative valence, whereas the present study demonstrated the threat advantage with non-social stimuli that can occur naturally in the environment, confirming the generality of the findings across different stimulus types.

Second, the contextual cuing effect was obtained when the contextual regularities were provided in task-irrelevant stimuli (threat and non-threat images) instead of the identity of search objects (Landolt squares). The results still demonstrated contextual learning, suggesting that the identifies of search objects are not critical. It should be noted that although the identities changed, the locations of distractors were constant when the contexts were fixed. Therefore, contextual learning may occur based on abstract semantic representations of search objects (i.e., "distractors") rather than specific instances (Goujon & Didierjean, 2007).

Third, threat detection did not affect learning of contextual regularities. If learning of contextual regularities required attention, it would have become more efficient when threat objects appeared within distractors because more attention was deployed to the context, but less efficient when threat objects appeared within the target because less attention would be deployed

to the context. However, the present results provided little evidence supporting this prediction.

Instead, the results supported the position that learning of contextual regularities does not require

attention (Jiang & Leung, 2005). Incidentally, the present experiment also tested the influence of

target-distractor similarity on the contextual cuing effect by comparing the effects for

homogeneous and heterogeneous displays. Although there was a larger context effect (the

overall advantage of fixed contexts to random contexts) for the homogeneous display than the

heterogeneous display (see also Conci & von Mühlenen, 2011), evidence is not unambiguous

because this effect did not interact with Block and there was no two-way interaction between

Target and Distractor Types. Thus, the results corroborate the previous finding that the target-

distractor similarity does not seem to affect contextual learning (Rausei et al., 2007), suggesting

that attention is not required for contextual learning.

It should be noted that a recent study reported that contextual learning was less efficient

when an image inducing negative emotion was presented before visual search (Kunar, Watson,

Cole, & Cox, 2014). The researchers suggested that a negative emotional state narrowed

attention focus and prevented from learning the global context. Although the present experiment

differed from that study because threat stimuli were present during, not before, visual search,

threat images could have induced negative emotion and narrowed attention focus. Possibly, this

did not occur because the presence of threat stimuli resulted in rapid shift of attention to these

stimuli before they induced negative feelings, so that the target were detected before narrowing

of attention occurred. In that case, negative feelings could have induced a minimal effect on

performance and learning. Similarly, a study showed that a salient singleton distractor reduced

the contextual cuing effect (Conci & van Mühlenen, 2009), which also suggests an impairment

of contextual learning when attention is disrupted from the context. Selective attention to a

subset of search objects can eliminate the contextual cuing effect by impairing the retrieval of learned contexts, not learning of the contexts (Jiang & Leung, 2005). Thus, it is interesting to see whether salient singleton distractors actually impairs learning or retrieval of learned contexts.

Overall, the present study indicates that factors guiding visual attention are different from factors that affect learning to guide visual attention. Researchers have suggested that threat detection may depend on automatic processes that filter visual information for threat values (Matthews & Mackintosh, 1998) or that monitor threat information and activate defensive behaviour (Öhman et al., 1999). These processes may be so efficient that they react preattentively to guide visual attention toward threat stimuli. Nevertheless, the present results indicate that the guided attention to threat stimuli does not contribute to learning of visual contexts containing them. The lack of the influence of threat detection on contextual learning may suggest that these threat values might not have entered memory traces as attributes of visual contexts. There has been reports that emotional events have a privileged status in memory, especially for those who suffer pathological conditions (Labar & Cabeza, 2006). Thus, it would be interesting to pursue implications of the present findings for the study of emotional memory in future investigations.

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Figure 1. Examples of the search array (A), and threat and non-threat stimuli (B) used in the experiment.

A.
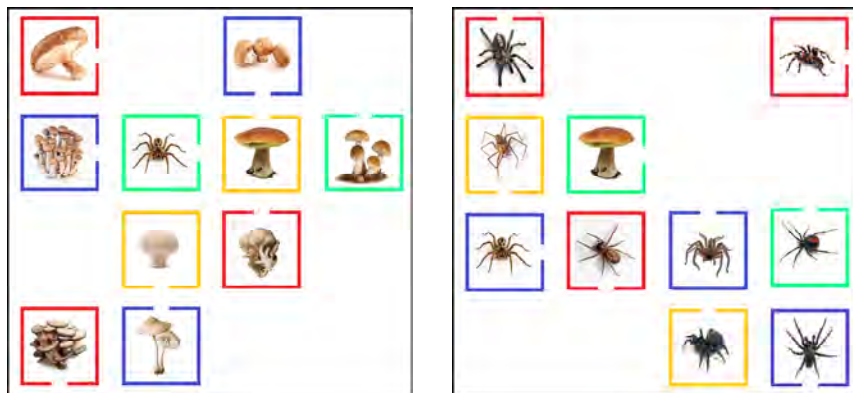
B.

Threat stimuli

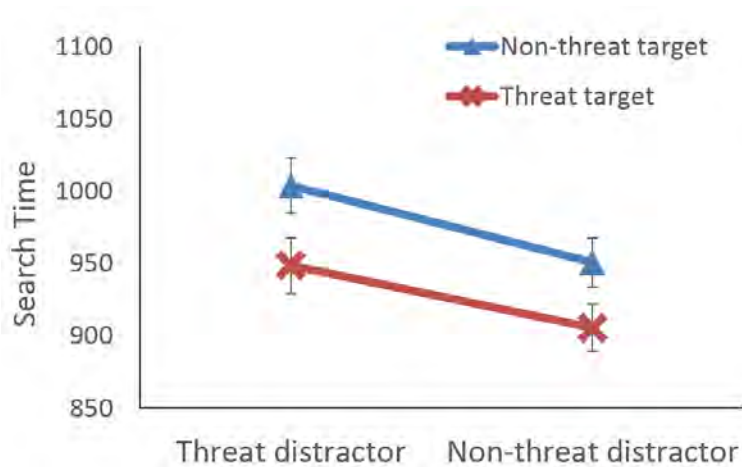**Non-threat stimuli**

Figure 2. Mean search time (in millisecond) as a function of Target and Distractor Types (A) and the context effect (differences in search time between fixed and random contexts) as a function of Block (1-6) and trend lines for the four combinations of Target Type and Distractor Type (B). Error bars represent one standard errors of means.

A.

B.