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Automatic and controlled attentional capture by threatening stimuli

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ABSTRACT

The rapid orienting of attention to potential threats would seem to proceed outside of top-down control. However, there is no convincing empirical finding that threatening stimuli only capture attention in a bottom-up way. The present study was designed to investigate the role of top-down and bottom-up processes in attentional bias to threats. We report a dot-probe experiment examining spatial cuing (valid and invalid) using threatening (spiders or snakes) or neutral (clownfish) stimuli in two conditions (predictable and unpredictable task). Forty-two students between the ages of 20 and 35 years participated in the study. They performed the probe detection task. Results suggested that threatening stimuli can capture attention, but this attentional effect cannot be regarded as totally bottom-up or automatic. We argue that attentional capture by threatening stimuli could be the result of a mechanism of attention shifting between bottom-up and top-down systems.

1. Introduction

Whether attentional capture is governed by bottom-up or top-down processes has been a longstanding debate in attention literature [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]. Currently, two opposed theoretical frameworks predominate in this debate: stimulus-driven theories [14, 15, 16] and goal-driven theories [17].

According to stimulus-driven theories, salient stimuli automatically capture visuospatial attention, regardless of a viewer's goals [18]. Theeuwes and colleagues [15, 16, 19, 20] argued that attentional capture is basically bottom-up and not subject to top-down control. Processing in early vision is driven exclusively by bottom-up factors such as salience, and only later could top-down factors play a role in processing [21].

In addition, stimulus-driven theories explain cases where salient stimuli produce no observable attentional capture effects, throughout the *rapid disengagement hypothesis* [16, 19]. According to this interpretation, attention is initially oriented to the most salient stimulus in the display, but the salient stimulus can then be rapidly rejected so that the target is attended with little delay [22].

In contrast to a stimulus-driven framework, goal-driven theories propose that goals and experiences of the individuals determine whether the salient stimulus can capture attention [17]. In other words, visual attention is guided to objects that have features matching what the observer is looking for (called an attentional set) [23].

Within this account, Folk, Remington and Johnston [17] also argued that attentional capture requires task relevancy, and therefore top-down attentional control tends to overwhelm bottom-up automatic attentional capture. According to their prospective, the so-called “contingent capture account”, attentional capture is completely subject to top-down control. Precisely, the ability of a stimulus to capture attention is contingent on whether an attentional-capturing stimulus is consistent with the top-down settings, which are established “off-line'' on the basis of current attentional goals. Hence, only stimuli that match the top-down control settings will capture attention; stimuli that do not match the top-down settings will be ignored [17].

Although stimulus-driven and goal-driven theories are two milestones in attention literature, recent research has revised the classical dichotomy between top-down and bottom-up processes by showing that these processes are not mutually exclusive and both can be active at the same time. For example, it was found that attention automatically captures stimuli that have previously been selected as targets and is biased toward stimuli that have previously provided useful information about events, or behaviors [16, 19, 20].

Moreover, the traditional dichotomy between top-down and bottom-up processes fails to explain a growing number of cases in which neither current goal nor physical salience can account for strong selection biases [24]. For example, it is well established that the visual system is biased towards quick and relatively automatic processing of threats [25, 26]. However, the extent of top-down attentional control processes on this bias is unknown.

Several studies have shown that pictures of threatening events, such as spiders and angry faces, are usually detected more quickly compared

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to neutral pictures [27, 28, 29]. Ohman's research [26] seems to provide compelling evidence that “threat perception” can automatically capture attention; moreover, the neuroscientific research of Vuilleumier and Righart [30] has provided even further support for this idea. However, in literature, the rapid orienting of attention to potential threats has been proposed to proceed outside of top-down control [31]. A recent study has highlighted the role of top-down goals in attentional orienting to, and disengagement from, threats [31]. Gladwin [32] examined the automatic capture of threatening stimuli using two variants of a dot-probe task with angry and neutral face cues. In the first variant, the task induced automatic biases. In the alternative variant, top-down control over attention occurred. Results showed an increase of attentional biases emotional stimuli in the alternative task, rather than a top-down effect.

Nevertheless, there is now no convincing empirical finding that threatening stimuli can only capture attention in a bottom-up way; many different paradigms that have been used to investigate attentional capture by threatening stimuli have provided evidence for both bottom-up and top-down capture [33, 34, 35]. Consequently, it is unclear whether and to what extent the top-down processes are involved in orienting to threats. What also remains unclear is whether attentional capture by threatening stimuli derives from a more effective top-down allocation of attention or from an involuntary, bottom-up capture of attention. Hence, a critical question remains: we can still question whether we process threatening stimuli in a way that is predominantly guided by automatic, bottom-up processes.

In this study, we investigated the role of top-down and bottom-up processes in attentional bias to threats using the dot-probe paradigm. The dot-probe task [36] is considered a gold standard in the field for investigating attentional bias to threats.

In order to explore attention capture by threatening stimuli, we examined spatial cuing (valid and invalid) using threatening (spiders or snakes) and neutral (clownfish) pictures in two conditions (predictable and unpredictable task). In the predictable task (PT), the cue stimulus was spatially predictable, and consequently could be used voluntarily for directing attention to a cued location, thereby bringing about larger attentional facilitation than for the unpredictable condition. This approach is commonly used to explore top-down processing. We are aware that, even in the PT condition, attention is not exclusively guided by top-down processes. As seen before, bottom-up and top-down processes are not mutually exclusive. Both can be active at the same time. In the predictable task, top-down attentional deployment is exerted on top of the bottom-up affordance of these stimuli, but both bottom-up and top-down processes are active during the predictable task. Since the bottom-up stimuli are present in both PT and UT conditions, the difference between results in UT and PT can show us the influence of the collaboration between top-down and bottom-up processes.

In the unpredictable task (UT), the cue had no predictive power as to the probe location, thus the probe was presented at either the cue or distractor location with equal probability. A facilitated response to probes that appear at the same location of the threat information in comparison with response to probes at the opposite location of threat stimulus would reflect a bottom-up attentional capture.

There were two main aims of the current study: a) to examine whether threatening pictures of snakes and spiders compared with neutral stimuli can automatically capture attention; b) to investigate whether these threatening pictures interfere with voluntary deployment of attention.

Few studies have explored the influence of spatial predictability on attentional bias to threats in healthy subjects. Notebaert, Crombez, Van Damme, De Houwer and Theeuwes [35] examined the role of spatial predictability in attentional bias to threat using a visual search paradigm. They used a fear conditioning procedure in which a previously neutral stimulus (colored circles) becomes a signal for an aversive stimulus, through electrocutaneous stimulus. They dissociated the threat value of a stimulus with a fear conditioning not predictive of the target. Their results indicated no complete automatic capture of attention by the fear conditional stimulus.

In light of previous studies, we were also interested in analyzing how a spatially predictable threatening stimulus compared with neutral stimulus might affect attentional prioritization and disengagement from threats.

2. Materials and methods

2.1. Participants

Forty-two psychology students at the University of Messina (21 males and 21 females) participated in the study as volunteers. Their ages ranged between 20 and 35 (M = 25.6; S.D. = 1.20). All had normal or corrected-to-normal vision, and reported not to be colour-blind. All participants gave their informed consent and were free to terminate the experiment at any time. No participant made use of this option. Prior to the start of the experiment, participants were asked to indicate how much they liked each picture (snakes, spiders, clownfish and flowers) used in the experiment, using a 7-point scale ranging from 1 (very unpleasant) to 7 (very pleasant). Based on the rating scores, eight subjects were excluded either because they indicated threatening pictures (snakes and spiders) to be relatively pleasant (i.e. $\geq$ 4 score) or neutral pictures (flowers and clownfish) to be relatively unpleasant (i.e. $<$3 score).

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. The Human Ethics Committee of the Cognitive Science, Education and Cultural Studies of the University of Messina approved the study protocol.

2.2. Stimuli

In accordance with previous studies [25, 26] one neutral and two threatening image types were used as cue stimuli. As with traditional spatial cueing paradigm, an image was designated as a cue; a valid cue showed the location of a probe stimulus (a filled white circle). However, the cue did not indicate higher predictability than chance coincidence in the unpredictable task. A different image was adopted as a distractor to be paired with the cue images: flowers were used as a distractor and three images of animals (i.e., spider, snake, and clownfish) were used as cues, see Fig. 1, Fig. 2, Fig. 3 and Fig. 4.

Spiders and snakes were cues of negative valence, while clownfish were of neutral valence. Each category consisted of 12 diverse images. Forty-eight diverse images were adopted in total. Twelve mask stimuli were set up cutting the images used into four segments - mosaic images were then formed from random reassembly, see Fig. 5.

A cue and a distractor pairing was shown at the centre of the screen, one image (either a cue or distractor) to the left of the fixation cross and

Fig. 1. Spider.

Fig. 2. Snake.

Fig. 3. Clownfish.

the other to the right. These were separated by a visual angle of 10.5 deg between the centres of the stimuli. Participants sat around 57 cm from the screen. A filled white circle, 0.3 diameter, acted as the probe stimulus.

The experiment was conducted using LabView Program of National Instrument. An IBM PC-compatible computer was used to present the stimuli and collect the responses.

2.3. Task

Two cueing settings were used to test participants: unpredictable task (UT) and predictable task (PT). They were first tested with non-informative cues from the UT, a block of 140 trials. The cue had no predictive power regarding the probe location, in this task. Consequently, the probe was presented with either the cue or distractor location with equal probability. Thus, when/if detected, an attentional effect was seen as the result of automatic capture by cue. Following a pause of several minutes, participants were tested in the informative cue setting, i.e. PT - the cue images correctly identified the target location in 80% of the trials when a probe was presented. Therefore, using the predictive information of the cue stimulus participants could direct attention to the cued location in a strategic way. This reflects a top-down processing. Thus, any attentional effect, if present, was attributed to the top-down capture by

Fig. 4. Flowers.

cue.

PT also consisted of one block of 140 trials. To ensure that there would be no possible carryover effects which voluntary use of the PT cue may have had on the non-informative cue, should the latter condition come after the informative cue, the PT was always presented after the UT. Consequently, the experiment started with the UT and was followed by the PT. This sequence also allowed us to prevent the informative cues effecting the results of the UT.

2.4. Procedure

Participants were placed in front of a CRT monitor and were exposed to visual stimuli composed of 12 pictures arranged in 12×4 categories, in two conditions (PT and UT). They were asked to respond to the probe as rapidly and precisely as possible pressing the space key with their right index finger, whereas, left-handed subjects had to press the space key with the index finger of the left hand. They were specifically told not to respond when the probe was not presented. The target was shown randomly to either the left or right of the fixation mark at the centre of one image. Prior to the start of the experiment, participants underwent a practice session of 10 trials: this included 140 trials (60 trials were in valid settings and another 60 were in invalid settings; 20 additional trials were used for catch, in which no probe appeared. Both the UT and the PT included these catch trials. A trial was valid when a cue picture (spiders, snakes and clownfish) predicted the target at the same spatial location (''valid'' trials), while it was invalid when the target was presented at the opposite spatial location of the cue (''invalid'' trials).

In a trial the event sequence was: Step 1, a fixation mark (+) was shown at the centre of the monitor where it remained during the trial. Step 2, the mask stimuli, one for each side of the fixation mark, were shown for 1500 ms. Both upper and lower sections of the mask stimuli stayed on the monitor, and the central parts were substituted by the cue and distracting images, which were were shown for 200 ms. Then they were then substituted by the mask stimuli, which were presented for 300 ms. At the end of the mask, a probe dot was shown at one mask location, which was left on the monitor until there was a response, or at the most for 1500 ms, and then shown no longer, see Fig. 6.

2.5. Design

This study employed a repeated measures design with three within

Fig. 5. Mask stimuli.

subjects variables 2 (predictability: predictable vs unpredictability) 3 (stimulus type: snakes, spiders and clownfish) X 2 (validity of the trials: valid vs invalid).

2.6. Statistical analysis

The data was analysed using SPSS 24.0 for Windows. The descriptive statistics of the dependent variables were tabulated and examined. The alpha-level was set to 0.05 for all statistical tests. In the case of significant effects, the effect size of the test was reported. The effect sizes was calculated using eta-squared. The Greenhouse-Geisser adjustment for nonsphericity was applied to probability values for repeated measures. The reliability of the reaction times and reaction time differences were measured using intraclass correlation coefficient (ICC).

Firstly, a repeated measures ANOVA with two within subjects variables 3 (stimulus type: snakes, spiders and clownfish) X 2 (predictability: predictable vs unpredictability) was used to verify the performance in both predictable and unpredictable tasks. Secondly, in order to evaluate the difference between top-down and bottom-up processing, a repeated measures ANOVA with three within subjects variables 2 (predictability: predictable vs unpredictability) X 3 (stimulus type: snakes, spiders and clownfish) X 2 (validity of the trials: valid vs invalid) was carried out.

3. Results

With reference to unpredictable condition, Table 1 shows the means and standard deviations of reaction times (RTs) according to the stimulus type and validity of the trials in the unpredictable condition. RTs higher than 1000 ms or less than 150 ms were excluded as outliers. The excluded trials were 10 (5%).

The "stimulus type" factor presented significant effect, $F (2, 34) = 6{,}92$; $p < .01$, $\eta^2 = 0.12$; RTs were faster when the probe appeared at the threatening picture than when it appeared at the neutral picture. This effect was not related to the location of the probe and consequently to deployment of spatial attention, rather it reflected a general increase in vigilance after having encountered a threatening stimulus. Subjects were simply faster in responding to the probe regardless of its location, because before they were exposed to threatening stimulus that increased their level of vigilance. This effect was not related to the attention capture of threatening stimulus rather to an increase of vigilance.

Post hoc analyses (Tukey honestly significant difference) revealed that both spider and snake stimulus types had significantly faster RTs than the clownfish stimulus type ($p < .001$, and $p < .03$, respectively). However, there was no significant validity X stimulus type interaction with respect to RT.

In this condition, the cue stimuli had no predictive power, thereby attention was captured automatically by threatening stimuli generating the fastest RTs. Moreover the validity factor show significant effect $F (1, 34) = 8.54$; $p < .01$, $\eta 2 = 0.22$; meaning that average reaction times were faster in "invalid" trials (i.e., if the probe appeared in location of the flower picture).

With reference to predictable condition, Table 2 shows the means and standard deviations of reaction times (RTs) according to the stimulus type and validity of the trials in the predictable condition.

Again, the "stimulus type" factor presented significant effect, $F (2, 34) = 45{,}1$; $p < .0001$, $\eta 2 = 0.23$.

Regarding the validity of the trials, the "validity x stimulus type" interaction was significant $F (2, 56) = 3.1$ $p < .05$, $\eta 2 = 0.09$; as we can see in Table 4 in which the attentional gain score across different stimulus types are considered, spiders had the smallest attentional gain score and the difference between valid and invalid trials is not significant, $t (39) = 1.91$ $p < .06$; with reference to snakes, the difference is significant, $t (39) = 2.92$, $p < .01$; finally, with reference to clownfish the difference between valid and invalid trials is also significant, $t (39) = 3.12$, $p < .01$.

In order to understand if there had been a decrease in the attentional effect due to interference with voluntary deployment of attention by the threatening images in the PT, demonstrated in the emotional Stroop effect (Williams Mathews and MacLeod 1996), attentional gain scores (AG) were calculated, for each setting (UT and PT), subtracting the valid RTs

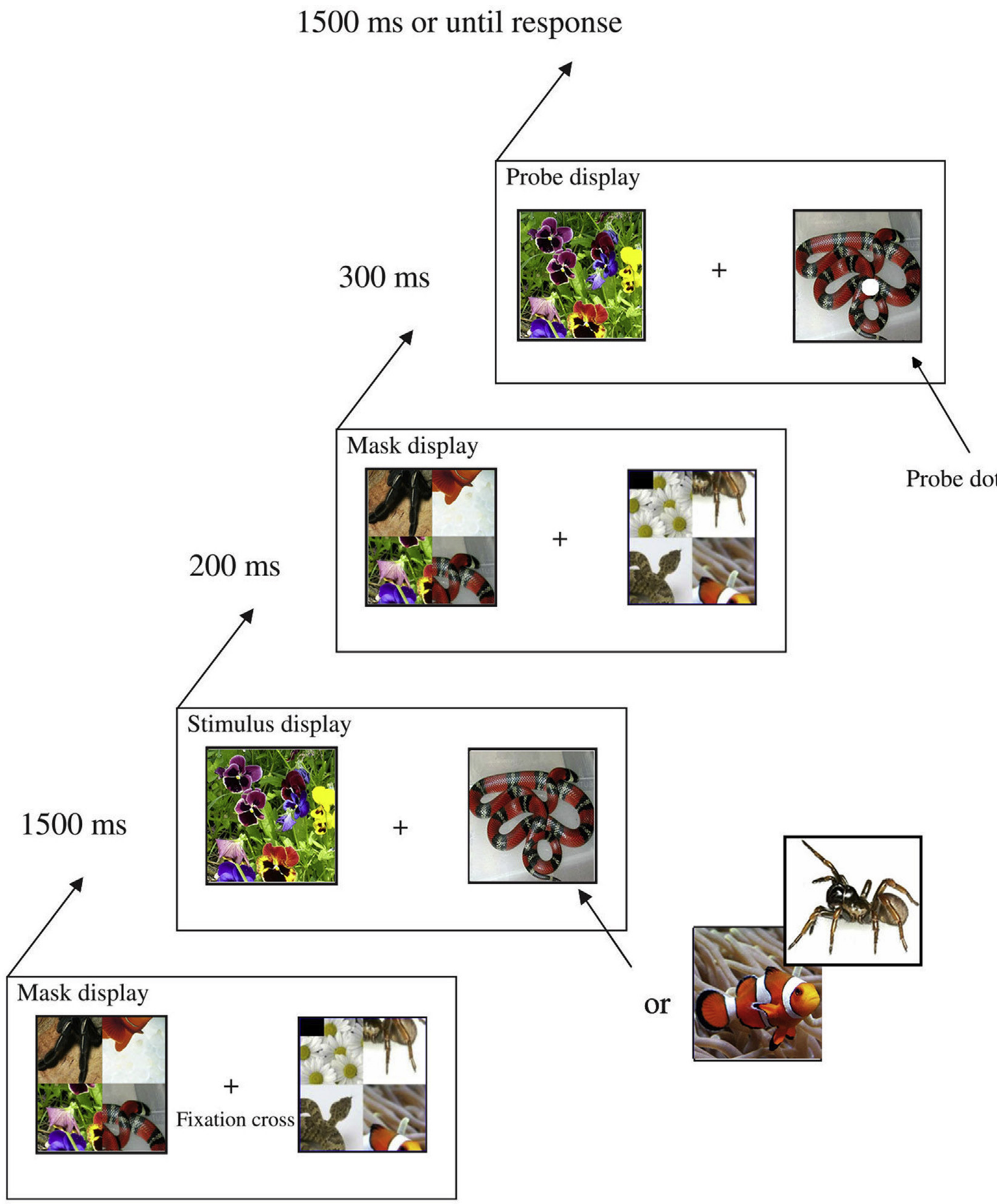

Fig. 6. Procedure.

Table 1
Means (M) and standard deviations (SD) of RTs according to stimulus type and validity in UT.

Stimulus type	Invalid		Valid	
	M	SD	M	SD
Spider	383.66	68.85	416.46	87.76
Snake	392.74	72.09	426.49	91.48
Clownfish	402.87	84.15	428.40	80.13

Table 2
Means (M) and standard deviations (SD) of RTs according to stimulus type and validity in PT.

Stimulus type	Invalid		Valid	
	M	SD	M	SD
Spider	425.85	71.08	366.15	61.92
Snake	437.72	87.47	368.07	64.72
Clownfish	440.05	79.69	374.67	56.12

from the invalid RTs (Tables 3 and 4). ICC shows values between 0.67 and 0.79.

In unpredictable condition, no significant effect of stimulus type on AG was found $F (1, 34) = 0.94$; $p < .34$, meaning that all three types of stimuli lose the same amount of RTs. Also in predictable condition, no significant effect of stimulus type on AG was found $F (1, 34) = 1.22$; $p < .09$. It may be that the threatening stimuli captured attention in a bottom-up way, and the flower stimuli attracted attention because they were pleasant for participants; indeed, the correlation coefficient of the subjects' pleasantness ratings with their attentional gain score was the following, $r (41) = .33$, $p < .05$.

By applying a repeated measures ANOVA with three within subjects variables 2 (predictability: predictable vs unpredictable) 3 (stimulus

Table 3
Means (M) and standard deviations (SD) relative to attentional gain scores of RTs in UT.

Stimulus type	M	SD
Spider	-32.80	33.47
Snake	-33.75	54.21
Clownfish	-25.53	26.45

Table 4
Means (M) and standard deviations (SD) relative to attentional gain scores of RTs in PT.

Stimulus type	M	SD
Spider	59.70	48.08
Snake	69.65	64.22
Clownfish	65.38	37.51

type: snakes, spiders and clownfish) X 2 (validity of the trials: valid vs invalid), the predictability × validity interaction also shows significant effect, $F(1, 56) = 23.34$; $p < .001$, $\eta 2 = 0.23$. This effect denotes that attentional gain scores differ between UT and PT: in the UT they are negative (i.e. bottom-up attendance to flower pictures vs. spiders, snakes, and clownfish) while in the PT they are positive (possibly due to an over-compensation of the bottom-up effects by top-down attentional control). Other effects did not reach statistical significance.

4. Discussion

There were two main purposes of the current study: to examine whether threatening pictures of snakes and spiders can automatically capture attention, and, to investigate whether these threatening pictures interfere with voluntary deployment of attention. Secondly, we were also interested in analysing how a spatially predictable threatening stimulus might affect attentional prioritization and disengagement from threats. In this experiment, the dot-probe task was employed, using threatening pictures of snakes and spiders or neutral images (clownfish) as cue stimuli in two conditions (PT and UT). The cueing stimuli could be valid and invalid in both conditions.

The results can be readily summarized. We found that when the stimulus was made predictive of the probe location, the performance was facilitated. This can be explained with top-down processing in which subjects voluntarily use the informative power of the stimuli for directing their attention to the cued location. Secondly, when the stimulus was made unpredictive of the probe location, it interfered with the voluntary deployment of attention, thereby engendering a reduced attentional effect for it. Thus, the bottom-up effect occured. We also found an unexpected effect of flower stimuli attracting attention. Because the flower stimuli captured attention in a bottom-up way and this effect was overcompensated by top-down attentional deployment during the PT, future research should include relatively unpleasant stimuli, for example: work tools, exercise books, tables and walls. Moreover, future studies could measure the index of pleasantness stimuli, check if this has a score around 4, and accept as neutral those stimuli obtaining a score between 3.5 and 4.

Lipp and Derakshan [37] investigated attentional bias to fear-relevant animals in 69 participants using a dot probe task showing pictures of snakes, spiders, mushrooms, and flowers. They found a preferential processing of fear-relevant stimuli in all participants, confirming the idea that threatening stimuli, such as snakes and spiders, automatically capture attention. Comparing this previous study with the present one, our results show that flower stimuli attract attention and threatening stimuli elicit also rapid attentional capture, but the effect of threatening stimuli dissipates when the task was made predictable, thereby suggesting a top-down effect. Therefore, we propose that these findings may be explained by a mechanism of attention shifting among bottom-up and top-down processes rather than by an exclusive bottom-up effect. In this explanation, top-down processes barely interact with bottom-up attention capture rather, they occur after them. Future research could examine collaboration between bottom-up and top-down processes in a probe task.

Moreover, it is interesting to note that in the current study attention was also captured by flower stimuli, used as control stimuli. This result is contrary to that of Lipp & Derakshan [37]. This result may be because the participants saw the flowers as something positive, i.e. there was a significant correlation between flower ratings and attentional gain score during UT. In addition, as described in the participant section of this study, the participants were asked to indicate their level of pleasantness of threatening pictures (snakes and spiders) and neutral pictures (flowers and clownfish). Based on these scores, participants indicating neutral pictures as being relatively unpleasant were excluded from this research. The final sample was composed of a non-anxious population with positivity biases; consequently, this factor could have promoted attention capture by flower stimuli. Future studies should verify this potential influence, comparing flower pictures with other neutral stimuli.

However, other factors should be taken into account. Firstly, it is difficult to determine, on the basis of the current results and existing studies, whether the initial shift of attention to the threat in the dot-probe task is specifically related to the emotional content of the stimuli or a threat perception per se. Indeed, our data suggests that automatic attention capture clearly occurred as we observed faster dot-probe performance when a snake or spider was present as an invalid cue than if an orange clownfish (neutral) was presented. However, this might be a Yerkes-Dodson Law effect. In other words, perhaps the snake or spider simply caused greater arousal (than the fish), and it was the greater cue-based arousal that affected dot-probe performance. Hence, this might be a salience-based effect, and had nothing to do with threat perception, per se. In order to verify the role of salient stimulus, an important direction for future research could be to separate salience from threats in order to obtain convincing results and overcome a limitation of the present study.

Another issue concerns whether these results reflect emotional arousal (a bottom-up effect) or emotional regulation (a top-down effect). Although it may not be fully possible to separate out emotional content from differences in low-level physical stimulus properties [38], future experiments could manipulate the emotional content of threatening and distractor stimuli in order to understand the relationship between attention and emotional regulation effects. In addition, future research could provide ERP data to understand better how top-down and bottom-up processes are involved in attentional capture of threatening stimuli.

In conclusion, the present study supports the idea that threatening stimuli are prioritized over other stimuli in order to ensure adaptive behaviour, but they do not automatically capture attention, as an attentional effect in both conditions was found. As aforementioned, the most appropriate conclusion is that the enhanced prioritization of threats is the result of attention shifting between bottom-up and top-down processes. We propose that attentional capture by threatening stimuli may be automatic by default, but can be either decreased or enhanced by endogenous attention processes, as the task demands. Hence, both bottom-up (automatic) and top-down (controlled) processes play an important role in attention responses to threatening stimuli.

Declarations

Author contribution statement

Rosa Angela Fabio: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Tindara Caprì: Performed the experiments; Contributed reagents,

materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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