

Spiders Crawl Easily Through the Bottleneck: Visual Working Memory for Negative Stimuli

Andrea Reinecke
Dresden University of Technology

Mike Rinck and Eni S. Becker
Radboud University Nijmegen

The special status of spiders in the attentional bottleneck and visual working memory (VWM) was studied. 23 spider-fearfuls (SF) and 23 non-anxious controls (NACs) participated in a serial VWM-task. Each trial showed a 4×4 matrix of images and 5 of these were subsequently cued for 150 ms each. Afterwards, one of the 16 displayed images was hidden and probed. The spider image was included in the string of 5 cued images, among the 11 uncued items, or not at all. For both groups, memory was better for cued spiders than for other cued items. SFs also showed improved memory for uncued spiders. The relevance of the results for theories of attention and cognitive models of phobias are discussed.

Keywords: attention, visual working memory, serial position effects, fear of spiders

Numerous experimental investigations suggest that humans consciously perceive only a fraction of the amount of information they believe to see at any single moment. For instance, experimental participants observing videotapes failed to notice the identity changes applied to a main figure (Simons & Levin, 1998) or the appearance of a gorilla in a ball playing scene (Simons & Chabris, 1999). Similar failures occurred when observers were working on a computer task, for instance, comparing the length of two line segments. When they were not told that another, task-irrelevant stimulus would shortly appear, about 25% of them failed to even perceive something unusual (Mack & Rock, 1998a, 1998b).

Wolfe, Reinecke, and Brawn (2006) have argued that these failures are due to the existence of two bottlenecks within the visual processing system: the attentional bottleneck and visual working memory. First, the attentional bottleneck is necessary to selectively attend to an object in order to fully identify and recognize it (e.g., Broadbent, 1958; Wolfe & Bennett, 1997). Remarkably, the attentional bottleneck seems to limit detailed processing to only a few, maybe even only a single object at any moment in time (Baylis & Driver, 1995a, 1995b; Tipper & Weaver, 1996). Second, visual working memory (VWM) is thought to hold the items most recently attended to (e.g. Hollingworth & Henderson, 2002) for several seconds, and it is limited to three or four items (Irwin, 1991; Irwin & Andrews, 1996; Luck & Vogel, 1997;

Wheeler & Treisman, 2002). In seven experiments, Wolfe et al. (2006) explored observers' memory for simple and complex scenes and the results supported the two-bottleneck hypothesis. In one experiment, attention and the input to visual working memory was guided and controlled by a cueing procedure. First, a 4×5 matrix of 20 items (i.e., colored squares) was displayed. Several items (e.g., 6 of the 20 items) contained in the matrix were then cued one after another. For each item, cueing was achieved by a sudden increase in luminance and size for 50, 150, or 300 ms. Subsequently, a single item was hidden by a gray square. Participants had to report the color of the hidden square. With this partial-report technique, the authors measured accuracy as a function of the serial position of the probed item within the cued string of items. Observers could reliably report only the one or two items that had been attended to most recently and, therefore, had passed the attentional bottleneck. With increasing "age" in visual working memory, accuracy decreased dramatically, such that items cued earlier in the string could not be reported well. Estimations of the capacity of visual working memory revealed a storage limitation to less than four items.¹ A similar pattern was reported by Irwin and Zelinsky (2002), suggesting generality of the effect.

The results described so far only relate to neutral stimuli, and none of the reported studies addressed the processing of emotionally relevant stimuli. This is regrettable because there is reason to suspect that emotional stimuli may be processed differently in the attentional bottleneck and in visual working memory. Indeed, many studies have shown an attentional bias for emotional, particularly threatening stimuli (e.g., Byrne & Eysenck, 1995; Öhman, Flykt, & Esteves, 2001; Rinck, Reinecke, Ellwart, Heuer, & Becker, 2005). This bias suggests that threatening materials may be preferably selected to pass the attentional bottleneck and be

Andrea Reinecke, General Psychology, Dresden University of Technology, Germany; Mike Rinck and Eni S. Becker, Clinical Psychology and Behavioral Science Institute, Radboud University Nijmegen, The Netherlands.

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Correspondence regarding this article should be addressed to Andrea Reinecke, Dresden University of Technology, General Psychology, D-01062 Dresden, FR Germany. E-mail: reinecke@psychologie.tu-dresden.de

¹ Wolfe et al. (in press) estimated the capacity of visual working memory by making the following assumption for each position of the cue string: (a) Accuracy = P(remembering the item) + (1-P(remembering)) × Empirical chance level, and (b) P(remembering) = capacity / string length. Solving for capacity leads to the formula: Capacity = Sum of [(Acc-Ch)/(1-Ch)] for all items of the cue string, where 'Acc' is the accuracy for each item in the list and 'Ch' is the empirical chance level.

remained in VWM. It is unclear, however, what exactly the nature of this selection is. Does it occur at the expense of other items within the visual field, or does it happen in some parallel form? And how are negative stimuli stored in visual working memory? Are negative stimuli saved preferentially, compared to non-negative materials? And are these processing biases stronger in or even restricted to individuals who suffer from phobic fear of the negative object?

The latter question is particularly relevant here because many studies have shown disorder-specific cognitive biases in anxiety disorders, in contrast to non-anxious control participants. Cognitive theories of anxiety postulate that biased cognitive processes play a dominant role in the etiology and maintenance of anxiety disorders (e.g., Beck, Emery, & Greenberg, 1985; Clark & Wells, 1995; Mogg & Bradley, 1998; Williams, Watts, MacLeod, & Mathews, 1997). According to these theories, anxiety disorders often involve disorder-specific, selective biases of attention and memory. The specific nature of these biases depends on the anxiety disorder under study (for a review, see Mathews & MacLeod, 2005). With regard to attentional processes in specific phobia, there is evidence that phobic individuals show enhanced detection of threat-related stimuli, greater distractibility by them, and aggravated disengagement of attention from them. For instance, spider phobics should be particularly good at detecting spiders; they should be easily distracted by spiders when trying to concentrate on other stimuli; and they should find it hard to disengage attention from spiders. Indeed, evidence for anxiety-related attentional biases has been provided by a large number of empirical studies employing a variety of experimental tasks (for reviews, see Mathews & MacLeod, 2005; Rinck & Becker, 2005; or Williams et al., 1997). Compared to attention, the empirical basis for phobia-related memory biases is less coherent, and many researchers failed to find disorder-specific memory biases in specific phobias (for reviews, see Becker, Roth, Andrich, & Margraf, 1999; Coles & Heimberg, 2002; Williams et al., 1997). In part, this may be explained by the finding that phobic patients avoid elaborating on threatening materials after they have shown an attentional bias to it (the vigilance-avoidance pattern of attention, e.g., Mogg, Bradley, Miles, & Dixon, 2004; Rinck & Becker, *in press*).

To summarize, many studies have addressed the two extremes of processing negative information: attention as our direct contact with the outside world and long-term memory as the longer-lasting storage of internal representations of the external world. There is wide agreement regarding attentional biases, but less coherence regarding memory biases. Surprisingly, however, very little is known about the processing of emotional stimuli at the link between attention and long-term memory, namely, the attentional bottleneck and visual working memory. Following Baddeley & Hitch (1974) and Baddeley (1992), working memory (WM) is a capacity-limited system retaining information for a few seconds. Within WM, verbal and visual information can be stored in parallel within the phonological loop and the visuo-spatial sketchpad, respectively. Moreover, the authors assume selective attention to stimuli as a prerequisite for their being selected into working memory. As there is convincing evidence that emotional stimuli draw attention (see above), they should also be more likely to be processed in working memory. Unfortunately, only a few studies focused on the investigation of selective effects of emotion on the attentional bottleneck and short-term memory. On the one hand, Kensinger & Corkin (2003) failed to find higher working memory accuracy for emotional stimuli. This negative finding is compro-

mised, however, by the fact that the emotional stimuli did not compete for attention with neutral stimuli presented simultaneously, a prerequisite for attentional biases to occur (Mathews & Mackintosh, 1998; Rinck & Becker, *in press*; Rinck et al., 2005). In contrast, Maljkovic & Martini (2005) revealed in a picture recognition task with varying encoding times that compared to neutral and positive pictures, images with negative valence are initially encoded more slowly, but then increasingly faster within 500 ms. Similarly, Anderson and Phelps (2001) demonstrated a preferential selection of aversive stimuli (e.g., the word 'rape' among neutral words) with an attentional blink paradigm. Their results suggest that threatening materials may be preferably selected to enter the attentional bottleneck, maybe even by the appropriation of additional resources.

Studying the bottlenecks between attention and memory in anxiety disorders may also shed some light on the conflicting results regarding memory biases in phobias. However, investigation of the bottlenecks requires a paradigm that addresses solely immediate memory for external stimuli. For this purpose, the visual working memory paradigm used by Wolfe et al. (2006) seems advantageous in several ways. First, it may employ pictures rather than words as ecologically relevant threat stimuli for participants suffering from animal phobias. Second, it specifically addresses visual storage of information, reducing the effect of verbal information on the attentional bottleneck. Third, the rapid serial presentation technique allows external guidance of attention and, by testing VWM contents directly after presentation, we may conclude which items passed the attentional bottleneck. Moreover, the serial presentation technique allows for measuring the effect of a negative item on the memorization of the items preceding and following it. Therefore, the experiment reported here used a serial visual working memory task that was very similar to the one used by Wolfe et al. (2006). The new feature introduced here was the inclusion of a negative stimulus. On every trial, 16 pictures were displayed simultaneously. Five out of the 16 pictures were cued one after another (yielding a "cue string" of five items) and, thereby, loaded into working memory. Directly afterwards, one of the 16 displayed items was hidden. The observer's task was to report the prior identity of the hidden target picture. We measured memory accuracy as a function of the position of the target object within the cue string. Different from Wolfe et al. (2006), we added a variation of image valence: In most of the trials, a single spider image was contained in the display. This negative object was either one of the five objects within the cue string or one of the eleven objects beyond the cue string. Furthermore, the spider image was the tested target object or another object was tested. Also, unlike Wolfe et al. (2006), we tested two extreme groups of participants: highly spider-fearfuls versus non-anxious controls.

The experimental task requires participants to maintain information in memory and to retrieve it at the end of each trial, but they do not have to elaborate on it. In fact, we may assume that the high cueing frequency does not allow for strategic processes such as verbalization or elaboration, thereby equating encoding conditions for all participants. We therefore predict that this memory task should be suitable for revealing enhanced immediate memory for negative materials in fearful participants. As the theoretical and empirical background regarding disorder-specific biases in visual working memory in spider phobia is very sparse, it is not easy to derive explicit hypotheses regarding participants' performance in this task. However, Baddeley (1992) proposes attention as a pre-

requisite for the storage of information in working memory and, as attentional biases to negative material were found in specific phobia, the results found in studies of attentional biases may be extended to visual working memory. Thus, we predict the following results: one, Spider images should be remembered better than non-negative images; two, Spider images should be remembered well, independently of their position within visual working memory; three, A spider picture should cause retroactive interference for items preceding it in the cue string and proactive interference for items following it; four, Spider images should be accurately remembered, even when their memorization is not demanded by the task, that is, when a spider image was presented, but not part of the cued string of items; five, The presence of a spider beyond the cued string should lead to lower memory accuracy to the cued non-spider items; six, These effects should be disorder-specific, that is, they should occur mainly or even exclusively in the spider fearful group.

Methods

Participants

Twenty-three spider-fearfuls (SFs) and 23 non-anxious controls (NACs) without any animal-oriented fears participated in the experiment. Potential participants were recruited after screenings in classes at several departments of Dresden University of Technology, using the German "Spider Anxiety Screening" (SAS; Rinck et al., 2002). Students with scores lower than 5 or higher than 14 (maximum 18) were invited for further interviews and testing. The SAS study by Rinck et al. (2002) had revealed a normative mean of 9.5 and a normative standard deviation of 6.9. Thus, both the NAC sample and the SF group were extreme groups (see Table 1). Before the experiment, these potential participants completed the German version of the "Fear of Spiders Questionnaire" (FSQ; Szymanski & O'Donohue, 1995; see Rinck et al., 2002) as well as the German FDD-DSM-IV inventory (Kühner, 1997), which is a translation of the "Questionnaire for Depression Diagnosis" (Zimmermann, Coryell, Wilson, & Corenthal, 1986). Moreover, interviewers trained in the use of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) checked the DSM-IV criteria for specific phobia concerning spiders. The interview was based on

the International Diagnosis Checklist for DSM-IV (ICDL; Hiller, Zaudig, & Mombour, 1997) including the eight-stage assessment scales of the F-DIPS (Margraf, Schneider, Soeder, Neumer, & Becker, 1996), which is the German version of the ADIS (DiNardo, Brown, & Barlow, 1994). For interviewers as skilled as the ones of this study, diagnoses based on this screening correspond well with diagnoses based on a structured interview (Janca, Robins, Buchholz, Early, & Shayka, 1992).

Depression (assessed with the FDD), alcohol abuse or drug abuse, and psychosis (assessed with screening questions) and specific phobia regarding other animals depicted during the experiment (assessed via ICDL) were exclusion criteria for participation in the study. Beyond that, no comorbidity was assessed. Only candidates reaching a minimum F-DIPS "fear score" of 4 and a minimum "avoidance score" of 3 regarding spiders qualified for the SF group. Moreover, they had to have a minimum score of 30 in the FSQ. Four of the 23 SFs fulfilled all DSM-IV criteria for a specific phobia of spiders. The remaining ones met all criteria except criterion E, which requires significant impairment in everyday life. Considering the relative ease of avoiding threatening spiders in Northern Europe, the lack of fulfilling this criterion is comprehensible and does not affect the questions of interest.

The SF group and the NAC group were matched with regard to age, gender, and educational level. All candidates had a high school degree and were students of Dresden University of Technology. On average, the 21 female and 2 male members of the NAC group were 21.0 years old ($SD = 1.9$), the 21 female and 2 male SF participants had a mean age of 21.2 years ($SD = 2.7$). All of the final 46 volunteers were without history of any psychiatric disorder and had normal or corrected-to-normal vision. All of them were informed of their rights as experimental participants and gave their consent. In return for their participation, they received course credit or a payment equivalent to \$5 per hour. After the diagnostics, all of the fearful participants were informed about behavioral therapy as a promising treatment for spider phobia. Those who were interested were given contact data of the Dresden University outpatient department for psychotherapy.

Materials and Apparatus

The experiment was controlled by MATLAB software using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Stimuli were presented on a gray background on 17" monitors with a resolution of 1024×768 pixels. Responses were recorded via mouse clicks. The displayed elements were 36 color images of a side length of 115 pixels: 1 spider image and 35 pleasant and neutral images, which were recommended by a team of experienced experts. The valence and arousal judgments given by our two groups subsequently to the experimental task yielded the following main results: Regarding *valence*, most stimuli were classified as pleasant (e.g., blossom, apple, basketball) or neutral (e.g., backpack, carton) without significant group differences. The one and only group difference was found for the spider image, which was judged as negative by the SF group ($M = 1.5$, $SD = 0.8$), but as neutral by the NAC group ($M = 4.6$, $SD = 1.4$). Regarding *arousal*, most images were judged as neutral (e.g., hat, pan), and some as mildly arousing (e.g., tree, candle). Only the spider image was judged as highly arousing by the SFs ($M = 7.7$, $SD = 2.3$), but as neutral by the NACs ($M = 5.4$, $SD = 1.0$), yielding a significant group difference. During the cueing phase of each trial, stimuli were presented in "matrices" made up of 16 images each: For each trial, 16 of the 36 images were randomly chosen and randomly allocated to the 16 locations of an invisible 4×4 grid. Within this invisible grid, the centers of the images were horizontally and vertically separated by 120 pixels. A sample matrix containing a spider image is shown in Figure 1B. During the response phase of each trial, the "response menu" was presented to the participants (see Figure 1D). It contained all 36 images at fixed locations that did not change during the experiment.

Procedure

Prior to the experimental session, participants were informed about the general procedure of the experiment, and they completed the State form of

Table 1
Questionnaire Scores (Means, Standard Deviations, *t* Tests)

	Spider fearfuls	Non-anxious controls	Significance of <i>t</i> test ($df = 44$)
Age	21.2 (2.7)	21.0 (1.9)	<i>ns</i>
SAS	18.8 (4.2)	1.7 (1.4)	.001
FSQ	60.7 (20.2)	2.3 (2.3)	.001
FDD	8.3 (4.5)	7.1 (5.2)	<i>ns</i>
STAI-T	42.1 (8.3)	38.8 (7.1)	<i>ns</i>
STAI-S pre exp.	37.6 (7.6)	34.2 (5.4)	<i>ns</i>
STAI-S post exp.	44.6 (9.6)	34.8 (5.7)	.001

Note. SAS = Spider Anxiety Screening; FSQ = Fear of Spiders Questionnaire; FDD = Questionnaire for Depression Diagnosis; STAI-T = State-Trait Anxiety Inventory-Trait; STAI-S pre exp. = State-Trait Anxiety Inventory-State before experiment; STAI-S post exp. = State-Trait Anxiety Inventory-State after experiment; *ns* = not significant.

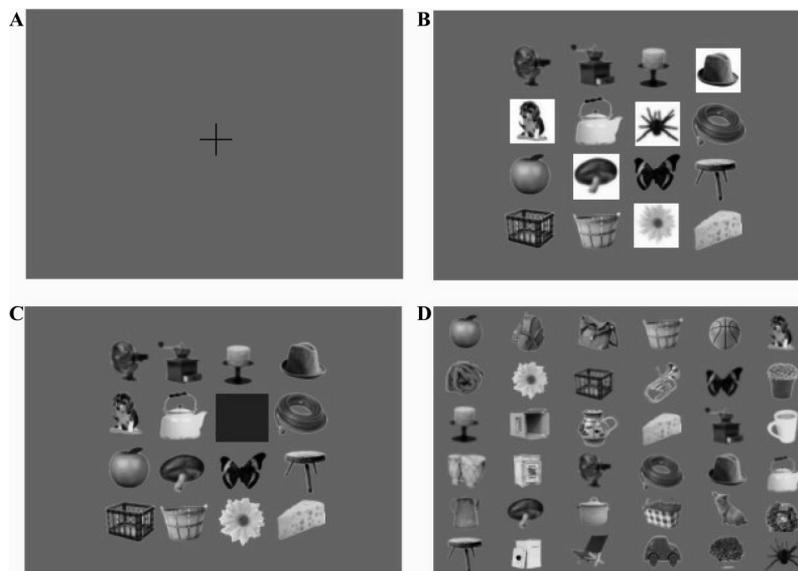


Figure 1. Sample trial with a spider image cued and probed. Subsequently to a fixation cross (A) and the appearance of the 4×4 stimulus matrix, five items are cued one after another (for simplicity, shown simultaneously here) by the appearance of a white frame (B). Immediately afterwards, one item is hidden under a gray mask (C). Participants' task is to specify the identity of the hidden target item in the response menu (D). Note: Actual stimuli were in color.

the German State-Trait Anxiety Inventory (STAI-S; Laux, Glanzmann, Schaffner, & Spielberger, 1981). After that, written instructions regarding the experimental task and a picture of the response menu were shown to familiarize participants with the materials. They were instructed to attend to the cue string to prepare for a memory test and then make a decision to indicate the target item. The importance of accuracy was emphasized. The computer screen was placed approximately 70 cm away from the participant. A sample trial containing a spider is shown in Figure 1. Each experimental trial started with the presentation of a black fixation cross on a gray background (see Figure 1A). After 500 ms, a 4×4 matrix of 16 images replaced the fixation cross. After another 500 ms, the cue sequence started: Five images were cued, one after another, at a fixed SOA of 150 ms. Cueing was achieved by showing a white square frame (side length 130 pixels) around the image for 150 ms. The cueing procedure is illustrated in Figure 1B (note: Figure 1B shows the five elements cued simultaneously, although they were cued successively). Immediately after the cue sequence, a single image (the target item) was masked by a dark gray square (side length 130 pixels, see Figure 1C) for 150 ms. Subsequently, the matrix was replaced by a blank gray screen for 1000 ms. Afterwards, the response menu (see Figure 1D) was displayed. Participants were asked to indicate the target item by mouse-clicking on the correct image included in the response menu. After the response, but no later than 3000 ms, the response menu vanished.² Written feedback was provided on screen after each trial. Participants initiated the next trial with a key press and, thereby, could take breaks whenever needed. After the experiment, participants completed the STAI-State questionnaire a second time, as well as the STAI-Trait questionnaire (STAI-T; Laux et al., 1981). Then they were asked to judge each of the 36 images on a 9-point rating scale with regard to its valence (1 = *unpleasant*, 9 = *pleasant*) and arousal (1 = *low*, 9 = *high*). Finally, the participants were debriefed about the aims of the study. A complete session took about 70 minutes.

Design

The task followed a $2 \times 7 \times 6$ factorial design with the between-subjects factor "participant group" (SFs vs. NACs) and the within-subjects factors "spider position" (cue 1, cue 2, cue 3, cue 4, cue 5, uncued, none) and "test position" (cue 1, cue 2, cue 3, cue 4, cue 5, uncued). "Spider position" refers to the location of the spider image: It could be one of the 5 cued images (with "cue 1" being the first cued image and "cue 5" the last one); it could be one of the remaining 11 uncued items; and "none" describes trials without any spiders. Similarly, "test position" refers to the probed target item, which could be one of the 5 cued images or any other uncued image of the matrix. We assumed the cued images to be the attended items, and uncued items were probed to test the effectiveness of the cueing procedure in directing attention. For each trial, spider position and test position were randomly chosen by the MATLAB experimental program. Each of the 42 possible combinations of spider position and test position was presented 10 times to each participant. Thus, they completed in total 420 experimental trials, preceded by six practice trials. For each factorial combination, the participants' mean accuracy in identifying the probed item served as the dependent variable. In the analyses of this variable, interactions involving the factor "group" were of main interest, because they would suggest disorder-specific effects. In contrast, main effects of spider position and test position would suggest general effects of negative materials on the attentional bottleneck.

² One might argue that the response procedure itself could be a source of errors due to search difficulty. Several arguments hold against that assumption. First, participants were familiarized with the response matrix before the experiment. Second, the response menu remained the same during the whole experiment and, therefore, allowed for learning. Third, during the development of the task as well as after the experimental sessions, we asked participants if they sometimes knew what the probed item was but were not able to give the right answer due to the temporary limitations. None of the participants ever affirmed this question.

Table 2
Mean Memory Accuracy (Percent Correct) and Standard Deviation (in Parentheses) for Each Experimental Combination of Participant Group, Spider Position, and Test Position

Group and spider position		Test position of target item					
		Cue 1 [A]	Cue 2 [B]	Cue 3 [C]	Cue 4 [D]	Cue 5 [E]	Uncued [F]
Spider-fearfuls							
Cue 1	[a]	.82 (.19)	.37 (.24)	.41 (.23)	.66 (.18)	.78 (.16)	.26 (.29)
Cue 2	[b]	.43 (.24)	.79 (.20)	.47 (.25)	.64 (.22)	.73 (.21)	.24 (.19)
Cue 3	[c]	.45 (.25)	.35 (.21)	.80 (.20)	.62 (.21)	.80 (.17)	.26 (.24)
Cue 4	[d]	.42 (.21)	.36 (.18)	.44 (.21)	.89 (.16)	.74 (.20)	.26 (.25)
Cue 5	[e]	.38 (.27)	.38 (.22)	.43 (.24)	.70 (.18)	.91 (.14)	.27 (.24)
Uncued	[f]	.45 (.20)	.36 (.20)	.42 (.18)	.70 (.17)	.76 (.14)	.62 (.27)
None	[g]	.43 (.24)	.42 (.22)	.47 (.24)	.69 (.18)	.83 (.11)	.28 (.23)
Non-anxious controls							
Cue 1	[a]	.71 (.26)	.37 (.21)	.40 (.22)	.60 (.27)	.70 (.22)	.18 (.18)
Cue 2		.48 (.27)	.62 (.24)	.34 (.23)	.62 (.23)	.74 (.18)	.19 (.14)
Cue 3	[c]	.44 (.23)	.36 (.22)	.69 (.22)	.62 (.20)	.74 (.16)	.22 (.22)
Cue 4	[d]	.47 (.27)	.33 (.23)	.40 (.23)	.78 (.21)	.68 (.22)	.17 (.15)
Cue 5	[e]	.48 (.25)	.34 (.20)	.40 (.22)	.62 (.20)	.86 (.18)	.20 (.21)
Uncued		.45 (.30)	.33 (.22)	.43 (.23)	.59 (.20)	.73 (.20)	.38 (.26)
None	[g]	.45 (.26)	.31 (.21)	.41 (.26)	.68 (.20)	.70 (.19)	.22 (.22)

Note. Combinations in which the spider picture was tested are indicated by boldface.

Results

Questionnaires

The mean questionnaire scores for the two groups of participants are shown in Table 1. Depression scores on the FDD, trait anxiety scores on the STAI-T-trait, and state anxiety scores on the pre-experimental STAI-S fell within the normal range and did not differ between the two groups. The SFs' state anxiety rose slightly during the experiment, yielding a significant difference between the two groups after the experiment. None of these results compromises interpretation of the results reported below.

Experimental Task

Prior to the statistical data analyses, practice trials were discarded from the data set. Table 2 shows the mean accuracy values in identifying the probed target object, separately for each experimental combination of spider position, test position, and participant group. The cells of Table 2 are labeled with letter combinations for ease of communication: Separately for each group, the lines are labeled a to g, and the columns A to F. We computed several specific analyses of the relevant experimental conditions, in order to separately test our specific hypotheses for varying

subsets of the data. Hypothesis six, regarding disorder-specific group differences, was tested together with each of the hypotheses one to five. We used an alpha-level of .05 for all statistical tests. To avoid inflation of alpha error in these analyses, Bonferroni corrections were used where necessary. Effect sizes are reported below as η^2 values for ANOVAs and as Cohen's (1988) d values for t tests.

Hypothesis 1: Spider images should be remembered better than non-spider images.

Following Wolfe et al. (2006) and Pashler (1988), we estimated VWM capacity values by subtracting a chance level of memory from the mean accuracy for conditions of interest (here: spider-free cue strings vs. strings containing a spider³) and, afterwards, multiplying the result by the cue string length of 5 items. As suggested by Wolfe et al. (2006), we estimated VWM capacity twice: once

³ VWM capacity values for items from spider-free cue strings were averaged across the 5 cells gA, gB, gC, gD, gE for spider-fearfuls and the same 5 cells for non-anxious controls. Values for cue strings containing a spider were averaged across the 25 cells aA-aE, bA-bE, cA-cE, dA-dE, and eA-eE for spider-fearfuls, and the same 25 cells for non-anxious controls.

using an empirical chance level and once using the theoretical chance level. The individual empirical chance level is represented by each participant's accuracy for uncued items in the specific condition of interest (non-spider vs. spider), the theoretical chance level equals 1/36 because the response menu contained 36 possible answers to choose from.

We computed two 2×2 ANOVAs on the capacity values in Table 3, once for the values based on the empirical chance level (ECL), once for the values based on the theoretical chance level (TCL). In both analyses, the factors were "cue string type" (spider-free strings vs. spider strings) and "group" (SFs vs. NACs). Similar to the results reported by Wolfe et al. (2006), the estimated capacity values ranged from 1 to 3 items. Regardless of the type of chance level used, VWM capacity was larger when a spider was among the items to be stored, ECL: $F(1, 44) = 8.92, p = .005, \eta^2 = .20$; TCL: $F(1, 44) = 5.35, p = .025, \eta^2 = .11$. This effect occurred to a similar degree in both groups, as there was neither a main effect of group, ECL: $F(1, 44) < 1, \eta^2 = .003$; TCL: $F(1, 44) = 1.49, p = .229, \eta^2 = .03$, nor an interaction, both $F(1, 44) < 1$, both $\eta^2 < .02$. The finding of increased VWM capacity for cue strings containing a spider raises a question: Does the presence of a spider enhance memory for all items of the cue string? Or is the beneficial effect limited due to superior memory for the spider item itself? To answer this question, the following additional analyses were computed.

Hypothesis 1 and 2: Spider images should be remembered better than non-spider images and should be remembered well independently of their position within the cue strings.

To more specifically test whether negative items have a favored role in visual working memory, we compared accuracy in spider-target trials (in which a spider was cued and also tested) to accuracy in spider-free trials (without a spider in the matrix).⁴ For this relevant subset of the data, we computed a $2 \times 2 \times 5$ ANOVA of the mean accuracy values, including the between-subjects factor 'group' (SF, NAC) and the within-subjects factors 'spider presence' (non-spider trials vs. spider trials) and 'test position' (Cue 1, 2, 3, 4, 5). The results are depicted in Figure 2.

The ANOVA revealed significant main effects for all factors: In total, SFs showed more accurate memory than NACs, $F(1, 44) = 5.92, p = .019, \eta^2 = .12$, and items shown just prior to the test were memorized better than items processed earlier, $F(4, 176) = 46.21, p < .001, \eta^2 = .51$. Moreover, spiders were memorized

better than non-negative images, $F(1, 44) = 79.32, p < .001, \eta^2 = .64$, and this was true for each of the five test positions, all $F(1, 44) > 14.46$, all $p < .001$, all $\eta^2 > .25$. The interaction of test position and group was not significant, $F(4, 176) < 1, \eta^2 = .02$, indicating that both groups showed similar serial position effects. The interaction of spider presence and group was not significant either, $F(1, 44) < 1, \eta^2 = .02$, suggesting that the two groups handled spider images in similar ways. The three-way interaction of group, spider presence, and test position was not significant either, $F(4, 176) = 1.55, p = .189, \eta^2 = .03$. In contrast, the interaction of spider presence and test position was highly significant, $F(4, 176) = 11.48, p < .001, \eta^2 = .21$, suggesting that the general serial position effect found in earlier experiments was weakened when negative rather than non-negative materials were involved. They were not completely erased, however, as they were still significant in one-way analyses of variance, both for SFs, $F(4, 88) = 5.37, p = .001, \eta^2 = .20$, and NACs, $F(4, 88) = 7.0, p < .001, \eta^2 = .24$. To test whether the significant main effect of 'group' was due to a general memory advantage of the spider fearful group, we computed additional two-way analyses of variance involving the factors 'test position' and 'group,' separately for spider-free trials and spider-target trials. For spider-free trials, there was no significant difference between SFs and NACs, $F(1, 44) = 1.89, p = .176, \eta^2 = .04$, whereas the analysis of the spider-target trials revealed higher accuracy values for the SFs, $F(1, 44) = 5.62, p = .022, \eta^2 = .11$. However, as mentioned above, this did not yield a statistically significant interaction of group and spider presence.

Hypothesis 3: A spider picture causes retroactive interference for items preceding it and proactive interference for items following it.

To test whether the presence of a spider image affects processing of neighboring items, we compared the mean accuracy in identifying non-spider images shown directly after or directly before a spider to non-negative images from corresponding trials without spiders. For analyses of items following a spider image, we used all trials that included a spider image in the cue string and in which the item directly after the spider was tested, yielding the "after spider image" condition. The corresponding cells of the spider-free trials were used as the baseline condition "after non-spider image."⁵ For these conditions, we computed a $2 \times 2 \times 4$ ANOVA of the mean accuracy values, including the between-subjects factor 'group' (SF, NAC) and the within-subjects factors 'item type' (after spider, after non-spider) and 'test position' (cue 2, 3, 4, 5). Memory accuracy for the probed non-negative item was significantly lower when it had been preceded by a spider item (NAC: $M = 0.51$; SF: $M = 0.55$) rather than a non-spider image (NAC: $M = 0.53$; SF: $M = 0.60$), $F(1, 44) = 4.98, p = .031, \eta^2 =$

Table 3
Mean Capacity Estimates From Memory Accuracy for Objects Within Spider-Free Cue Strings vs. Spider Strings, for Both Participant Groups

Chance level type and string type	Group	
	NAC	SF
Empirical chance level		
spider-free strings	1.4	1.4
spider strings	1.8	1.6
Theoretical chance level		
spider-free strings	2.4	2.7
spider strings	2.6	2.8

Note. NAC = non-anxious controls; SF = spider-fearfuls.

⁴ The relevant spider-target trials are given in the 10 cells for which test position equals spider position (cells aA, bB, cC, dD, eE for each group), shown in bold face in Table 2. The corresponding spider-free trials are shown in the 10 cells defined by the 2 lines labeled "Spider Position None" and the 5 columns labeled "Cue 1" to "Cue 5" (cells gA, gB, gC, gD, gE for each group).

⁵ For the "after spider image" condition, we included the cells aB, bC, cD, and dE for each group. The corresponding cells of the spider-free trials were gB, gC, gD, and gE for each group.

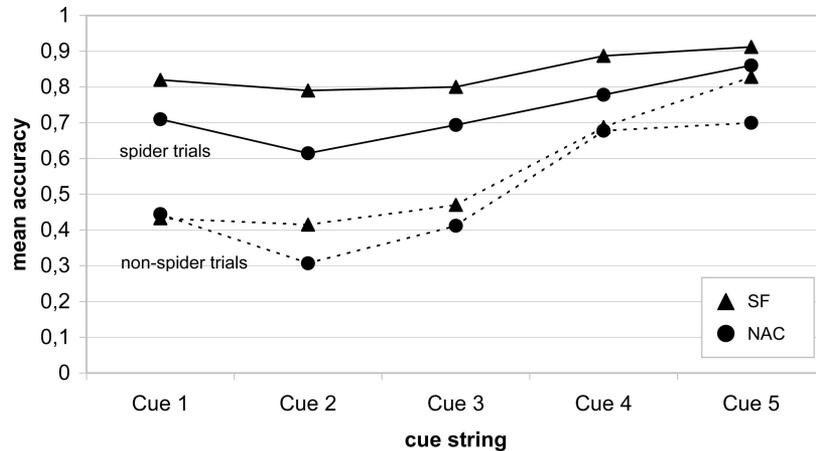


Figure 2. Serial position effects: Mean memory accuracy for spider targets vs. non-spider targets, depending on group and position within the cue string.

.10. Moreover, as already shown, the target item's position within the VWM also affected memory accuracy, $F(3, 132) = 73.10, p < .001, \eta^2 = .62$. We failed to find a significant main effect of group, $F(1, 44) = 2.0, p = .165, \eta^2 = .04$, an interaction of item type and group, $F(1, 44) < 1, \eta^2 = .02$, or a three-way interaction of group, item type, and test position, $F(3, 132) = 2.06, p = .109, \eta^2 = .05$, suggesting that spider images interfered with memorization of the immediately following item to a similar degree in both groups. Moreover, the observed proactive interference effect was short-lived: For the second item following a spider image, the main effect of item type was not significant, $F(1, 44) = 2.02, p = .163, \eta^2 = .04$. This suggests that the distractive effect of the spider image on memory accuracy for following images vanished within 150 ms.

Similar analyses were computed for the non-negative item preceding the spider image and the corresponding control items. Again, a $2 \times 2 \times 4$ analysis of variance with the factors 'group,' 'item type' (preceding spider, preceding non-spider), and 'test position' (cue 1, 2, 3, 4) was computed. This analysis did not yield significant effects, except for the already known main effect of 'test position', $F(3, 132) = 46.94, p < .001, \eta^2 = .52$, suggesting that the spider image did not cause retroactive interference.

Hypotheses 4 and 5: Spider images should be accurately remembered, even when they are not cued.

The presence of a spider beyond the cued set should lead to lower memory accuracy for the cued non-spider items.

(A) *Memory for uncued spiders vs. non-spiders.* To find out whether there is any memory advantage for spiders outside the cue string, even though these are not cued, and whether this advantage is specific to spider-fearfuls, we compared the mean accuracy in reporting (a) the probed spider beyond the cue string to (b) the probed item beyond the cue string in non-spider trials.⁶ These values were subjected to a 2×2 ANOVA involving the between-subjects factor 'group' and the within-subjects factor 'test item' (spider, non-spider). The resulting means are depicted in Table 4(A). There was a significant main effect of 'negativity,' $F(1, 44) = 40.0, p < .001, \eta^2 = .48$, indicating that uncued spider items were memorized better than uncued non-negative items.

Additional t tests confirmed this result for both groups, NAC: $t(22) = 3.26, p = .004, d = .67$ and SF: $t(22) = 5.49, p < .001, d = 1.32$. Moreover, we found a significant main effect of 'group,' $F(1, 44) = 6.09, p = .018, \eta^2 = .12$, and a significant 'group' \times 'negativity' interaction, $F(1, 44) = 5.08, p = .029, \eta^2 = .10$. This interaction was based on significantly better performance of SFs than NACs for spider items, $t(44) = 3.05, p = .004, d = .91$, compared to a non-significant difference between the two groups for non-negative items, $t(44) < 1, d = .31$. Thus, compared to NACs, SFs showed a pronounced memory advantage when uncued spider items were tested.

(B) *Memory for uncued spiders vs. cued non-spiders.* Is the SFs' memory advantage for uncued spider items strong enough to outweigh the effect of cueing for non-negative items? That is, are uncued spiders reproduced as well as cued non-negative items or maybe even better, although they were not exogenously cued? The answer to this question would yield interesting information about the relative size of the memory advantage for spiders, over and above its mere statistical significance. To answer this question, we compared mean accuracy in remembering uncued spider items to mean accuracy in remembering cued items in non-spider trials.⁷ For this subset of the data, we computed a 2×2 ANOVA of the mean accuracy values, including the between-subjects factor 'group' and the within-subjects factor 'probe' (cued non-spider item, uncued spider item). The results are depicted in Table 4(B). The ANOVA did not reveal a main effect of 'probe,' $F(1, 44) = 1.05, p = .311, \eta^2 = .02$, suggesting that on average, neither uncued spiders nor cued non-spider items were better reproduced. In contrast, there was a highly significant main effect of 'group,' $F(1, 44) = 8.77, p = .005, \eta^2 = .17$, and a significant 'group' \times 'probe' interaction, $F(1, 44) = 5.57, p = .023, \eta^2 = .11$. Subsequent t -tests revealed the nature of this interaction: NACs' mem-

⁶ For (a), the values of the two cells labeled fF are relevant, for (b), the two cells labeled gF are of interest.

⁷ The mean accuracy in remembering uncued spider items is depicted in the two cells labeled fF, the 10 relevant cells for calculating the mean accuracy in remembering cued items in non-threatening trials are labeled gA, gB, gC, gD, and gE for each group.

Table 4
Comparisons of the Mean Memory Accuracy (Percent Correct) and Standard Deviation (in Parentheses) of Specific Cued vs. Uncued Conditions

Experimental conditions	Group	
	NAC	SF
A) Uncued no-spider items	.22 (.22)	.29 (.23)
Uncued spider items	.38 (.26)	.62 (.27)
B) Cued no-spider items	.51 (.14)	.57 (.15)
Uncued spider items	.38 (.26)	.62 (.27)
C) Cued spider items	.73 (.17)	.84 (.15)
Uncued spider items	.38 (.26)	.62 (.27)
D) Absence of an uncued spider item	.51 (.14)	.57 (.15)
Presence of an uncued spider item	.51 (.16)	.54 (.13)

Note. A) Mean memory accuracy and standard deviation for uncued no-spider items vs. uncued spider items. B) Mean memory accuracy and standard deviation for cued no-spider items vs. uncued spider items. C) Mean memory accuracy and standard deviation for cued vs. uncued spider items. D) Mean memory accuracy and standard deviation for cued non-spider items, depending on the absence or presence of a spider item among the non-cued items. NAC = non-anxious controls; SF = spider-fearfuls.

ory performance was better for cued non-negative items, $t(22) = 2.55$, $p = .018$, $d = .65$, whereas SFs showed a minor and non-significant advantage for uncued spider items, $t(22) < 1$, $p = .382$, $d = .24$.

(C) *Memory for cued spiders vs. uncued spiders.* The latter result suggests that for SFs, the negative value of spiders produces effects that are at least as strong as the cueing effects for non-spider items. Therefore, one may wonder whether cueing has an effect for spider items at all: Are uncued spider images remembered just as well as cued ones? To answer this question, we computed a 2×2 ANOVA involving the between-subjects factor 'group' and the within-subject factor 'cueing status' (cued spider, uncued spider). For this analysis, we determined mean accuracy for cued-and-probed spiders and mean accuracy for uncued-and-probed spiders.⁸ The resulting means are depicted in Table 4(C). Significant main effects were found for both factors, indicating that cued spiders were better memorized than uncued spiders, $F(1, 44) = 91.23$, $p < .001$, $\eta^2 = .68$. Subsequent t-tests showed that this cueing effect occurred both for NACs, $t(22) = 7.91$, $p < .001$, $d = 1.63$, and SFs, $t(22) = 5.50$, $p < .001$, $d = 1.05$. A significant main effect of 'group' indicated that SFs showed better memory performance than NACs for spiders images, $F(1, 44) = 9.41$, $p = .004$, $\eta^2 = .18$. This difference in favor of the SFs occurred both for uncued spiders, $t(44) = 3.05$, $p = .004$, $d = .91$, and for cued ones, $t(44) = 2.37$, $p = .022$, $d = .69$. The advantage was larger for uncued ones, however, yielding a significant 'group' \times 'cueing status' interaction, $F(1, 44) = 4.53$, $p = .039$, $\eta^2 = .09$. This result suggests that in addition to paying attention to the cued items, spider-fearfuls also paid attention to a spider that occurred beyond the cue string.

(D) *Distraction caused by uncued spiders.* The previous analysis revealed improved memory for uncued spiders in SFs. This raises the question whether this improvement comes at the cost of memory for cued items, or whether SFs somehow manage to remember the uncued spider in addition to the cued items. To answer this question, an additional analysis was computed to find out whether the presence of a spider image beyond the cue string affected memory accuracy for non-negative items within the cue string. Here, we compared mean accuracy for non-negative cued items when there was a spider beyond the cued string to mean accuracy for the same items when there was no spider beyond the cued string.⁹ The results of the 2×2 ANOVA involving the between-subjects factor 'group' and the within-subjects factor 'presence of uncued spider' (present, absent) are depicted in Table 4(D). This analysis did not reveal any significant effects, neither for the main effects, both $F(1, 44) < 1.27$, nor for the interaction, $F(1, 44) = 0.77$, $p = .384$, $\eta^2 = .02$, suggesting that memory for cued items was not impaired by the presence of a spider image outside the cue string. The latter was true for both groups, NACs: $t(22) < 1$, $d = .0$ and SFs: $t(22) = 1.39$, $p = .179$, $d = .21$.

Alternative Explanation 1: A Response Bias for Spider Images in Spider-Fearfuls

An alternative account of the findings described above states that the observed group differences were due to a general response bias in the spider fearful group, rather than a disorder-specific memory bias. To test this hypothesis, we intended to calculate the signal detection parameters d' and β . To this end, we determined hit rates (uncued item is correctly reported as a spider) and false alarm rates (uncued item is wrongly reported as a spider) for both groups in two conditions: when a) there was a cued spider within the display, and b) when there was no spider within the display. Unfortunately, a formal signal detection analysis was not possible because the requirements were not fulfilled: False alarm rates were very low and even at zero for over one third of participants. However, an informal inspection of the mean hit rates and mean false alarm rates suggested that SFs did not have a response bias in favor of spiders: They achieved much higher hit rates than NACs (62% vs. 38%), but had the same low false alarm rates (a) 8% vs. 9% and b) 3% vs. 2%).

Alternative Explanation 2: Psychophysical Uniqueness of the Spider Image

An alternative explanation of the memory enhancement that both groups showed for spiders refers to psychophysical features of the spider picture, rather than its emotional valence. The spider picture is one of the most salient ones, due to its dark color, very distinctive star-like pattern, and its depiction as an animal. To test this explanation, we compared the hit rate for the spider image to

⁸ The 10 relevant cells for the mean accuracy for cued spiders are those at the diagonals: aA, bB, cC, dD, and eE for each group. The mean accuracy for probed spiders beyond the cue string is depicted in the 2 cells labeled fF.

⁹ For the condition "spider beyond the cued string", the cells fA, fB, fC, fD, and fE from each group were relevant. For the condition "no spider beyond the cued string", we used cells gA, gB, gC, gD, and gE from each group.

the hit rate for the butterfly image, because the butterfly image used in this task was also dark and characteristic in shape. Moreover, it also depicted an animal, but a positively valenced one. The 2 (picture) \times 2 (group) ANOVA of these hit rates revealed a significant main effect of the picture in favor of the spider image (hit rates spider: NAC $M = 0.64$ /SF $M = 0.80$; hit rates butterfly: NAC $M = 0.48$ /SF $M = 0.51$), suggesting that the memory enhancement for spiders is not solely attributable to psychophysical characteristics.

Discussion

In the experiment reported here, we used an experimental task introduced by Wolfe et al. (2006), in order to study how negative items affect the attentional bottleneck and visual working memory. In this task, a matrix of images is shown simultaneously; a rapid serial cueing technique is used to externally guide attention to some images; and VWM content is probed directly after cueing. The effect of emotionally valenced materials, particularly negative materials, was tested by including a spider image in the matrix, either among the cued items or outside the cue string. In order to vary the threat value of the spider image while holding the image constant, a group of highly spider fearful participants (SFs) was compared to a group of non-anxious controls (NACs). The observed results extend earlier ones reported for emotionally neutral materials to the processing of negative materials. At the same time, they extend the literature on cognitive biases in specific phobias to processes affecting the attentional bottleneck and visual working memory.

In summary, the experiment yielded a number of noteworthy results regarding visual working memory for cued and uncued items. Regarding cued items, we found that negativity widened the attentional bottleneck and increased visual working memory capacity: Capacity values, as computed by conventional formulas, were larger for cue strings containing a spider than for strings without a spider. This was true both for SFs and NACs. This result is compatible with many earlier ones that showed a general processing advantage for evolutionary relevant stimuli which signal danger or used to do so, for example, spiders, snakes, crocodiles, or heights (for an overview of studies, see Öhman & Mineka, 2001, 2003). It has been argued that humans are predisposed to be alert of situations and animals that, during early stages of evolution, endangered survival. In fact, in conditioning experiments, these evolutionary "old" threat stimuli are more easily associated with fear (Öhman & Mineka, 2001, 2003) than modern stimuli (e.g., cars, weapons), and they are more often at the core of phobic fears (McNally, 1987).

Second, we found that the participants' increased VWM capacity for spider strings was due to improved memory for the spider image itself, whereas the item following the spider was remembered worse than other items. Thus, the spider image caused proactive interference, and this interference was also found for SFs and NACs alike. Moreover, the two groups were also comparable in that retroactive interference occurred in neither group, that is, memory for the item preceding the cued spider image did not suffer compared to other items. The lack of retroactive interference in the presence of proactive interference suggests that participants found it difficult to disengage their attention from the spider image, and that prolonged processing of the spider image interfered with attention to the subsequently cued image. Difficulties in

disengagement of attention have recently been suggested as a major cause of attentional biases toward threat in high trait anxiety and anxiety disorders (Fox, Russo, Bowles, & Dutton, 2001). In our study, however, it occurred to a similar degree in both SFs and NACs.

Third, we replicated the central results of Wolfe et al. (2006) by finding strong serial position effects for non-negative items in spider-free trials. For these materials, observers were solely able to maintain the identity of recently attended items. As depicted in the serial position curves, there was high memory accuracy for the two latest items stored in visual working memory and declining accuracy for earlier items, while accuracy was generally poor for uncued items. Thus, in neutral picture displays, response accuracy seems to be severely limited by the two bottlenecks suggested by Wolfe et al. (2006): The bottleneck in selective attention restricts the ability to report the identity of items to the recently attended ones. Additionally, the VWM bottleneck limits these to a maximum of three items. As one would expect, this was true for both NACs and SFs, because the cue strings did not involve any spiders. In contrast, the serial position effect was much weaker for cue strings containing a spider image, suggesting that the effect was attenuated by negative emotional valence. The attenuation was due to improved memory for the serial position that contained the spider image. Therefore, when a negative item is cued, the two bottlenecks do not seem to function in the familiar manner. Instead, they seem to be widened: spider images are better memorized than non-negative images, and the position of the spider image within VWM is less important than it is for non-spider items. In fact, we found that for each position of the cue string, accuracy for the spider image was higher than for non-negative items at the same position. Therefore, whenever a spider image was included in the string of five cues, the serial position curve would show a clear peak at the position of the spider, reminiscent of the Restorff effect (Restorff, 1933). The resulting curves looked quite different from the serial position curve found in earlier experiments with neutral materials (Irwin & Zelinsky, 2002; Wolfe et al., 2006). Averaging over the five possible positions of the cued spider then yielded the high and flat curves shown in Figure 2. The widening of the bottlenecks and the attenuation of position effects by the spider occurred for both SFs and NACs.

In contrast to the cued items, the negativity effects for uncued items varied with fear of spiders, yielding several reliable group differences. First, uncued spiders were better recalled than other uncued items and this bias toward uncued spiders was stronger in SFs. Indeed, for SFs, the advantageous negativity effect for uncued spiders was not only statistically significant, it was also just as strong as the cueing effect for neutral items. This was not the case for NACs. The beneficial negativity effect did not erase cueing effects for spiders, however, such that even SFs recalled cued spiders better than uncued ones. Finally, the SFs' memory advantage for uncued spiders did not come at the cost of the cued non-spider items. Instead, they managed to remember the cued items just as well as NACs did, while simultaneously showing improved recall of uncued spiders.

The observed pattern of results suggests general effects which occur in highly fearful participants and non-anxious ones, as well as disorder-specific effects, which occur in fearfuls only. Interestingly, the boundary between general and specific effects is defined by the cueing procedure: For cued items, we found that both SFs and NACs showed improved memory for the spider image,

whereas only SFs showed improved visual working memory for uncued spider images. The lack of reliable differences between SFs and NACs with regard to cued items is quite plausible in light of earlier research. Several studies have shown that anxiety patients show hardly any processing advantage for threat stimuli when—as in the present cueing procedure—attention is voluntarily focused on specific items. This pattern of results is in accordance with theoretical predictions (most clearly formulated by Mathews & Mackintosh, 1998), and it was found in a variety of experimental tasks, for instance, signal detection tasks (e.g., Becker & Rinck, 2004; Windmann & Krüger, 1998), visual search tasks (Rinck et al., 2005), and in free viewing situations (Hermans, Vansteenwegen, & Eelan, 1999, Rinck & Becker, in press). The same applies to the visual working memory task used here: Participants were asked to focus their attention on the cued items, which were cued one by one and, as a result, no disorder-specific processing advantage for SFs occurred. Whatever advantage the negative value of the spider image may have had for SFs, the NACs were able to compensate for it by voluntary allocation of attention.

One might also wonder why the NACs behaved in this way and showed improved memory for the cued spider image, although they did not rate it as significantly negative. Does this mean that stimulus features of the spider other than negativity caused the effects observed for NACs? Or does this cast doubt on subjective ratings and other direct estimates of emotional valence? Most likely, the latter is true, because recent findings suggest that indirect effects of negative stimuli are likely to be observed even when participants' direct ratings do not reflect the negativity (Ellwart, Rinck, & Becker, in press; Greenwald, McGhee, & Schwartz, 1998). These dissociations between direct measures (e.g., evaluations) and indirect ones (e.g., reaction times and memory performance scores) have recently become a topic of considerable interest. For instance, Greenwald et al. (1998) demonstrated that white participants may show negative associations toward black faces, although they deny racial prejudices when asked directly. And more closely related to the present study, Ellwart et al. (in press) found that even participants who reported no fear of spiders at all showed significant spider-fear associations, which were only slightly weaker than those of spider phobics. In conclusion, the memory advantage for spiders observed in NACs fits in well with these previous findings, it extends them to a working memory task and it points to the importance of dissociations between direct and indirect measures of emotional valence.

In contrast to the cued items, no attention had to be paid to the uncued ones, thereby directing voluntary attention away from them. Moreover, there were 11 uncued items presented simultaneously. In this situation, there is strong competition for attention, which has been identified as a prerequisite for finding attentional biases toward threat in anxiety patients (e.g., Mathews & Mackintosh, 1998; Rinck & Becker, in press). In this situation, uncued negative items function similarly to threatening distractor items in a visual search task, for which an attentional bias has been shown repeatedly (see Rinck et al., 2005): Stimuli that are threatening to anxiety patients capture their reflexive attention (for detailed accounts of attentional processes including voluntary vs. reflexive processes, see Posner, 1980; or Posner & Peterson, 1990). Anxiety patients may show this reflexive attentional bias toward threatening stimuli because of their increased experience with the feared objects. Following Cave and Batty (2006), mere practice allows for the construction of stronger connections be-

tween high-level representations of objects and the specific combination of its visual features. Similarly, the authors assume that anxiety representations are more highly activated in anxious participants, therefore the perception of threat items is improved by the individual's numerous experiences of searching for the feared object. Similarly, Öhman et al. (2001) also suggest that individual fears and attitudes influence attentional processes.

Although the SFs' improved memory for uncued spider images is quite plausible for theoretical and empirical reasons, a puzzle remains: Why does it not come at the cost of memory for the cued items? This seems to suggest that in some mysterious way, SFs were able to recruit additional attentional resources in order to process uncued spider images, over and above the cued items. However, the accuracy rates shown in Figure 2 suggest something different: For non-negative cue strings (the "non-spider trials" of Figure 2), both SFs and NACs showed fairly low accuracy rates. Even for the most recently cued item, accuracy rates were only between 70% and 80%. This suggests that the participants did not spend 100% of their attention on the cued items, but also paid some attention to other aspects of the task, the materials, or the environment. This could happen during the 750 ms of the cueing procedure as well as during the preceding 500 ms. It does not seem unlikely to assume that NACs distributed their attention more evenly among the non-cued items than SFs, whose attention—for the reasons outlined above—tended to be captured by uncued spiders. As a consequence, they outperformed the NACs when an uncued spider was probed. Thus, we would like to argue that there is no need to assume some mysterious additional attentional resource for the processing of negative stimuli, over and above the widening of the attentional bottleneck and visual working memory that was observed for cued items.

Several limitations of the current experimental design should also be noted. First, there were no other images with negative valence in addition to the spider image. Thus, one has to be cautious in attributing the observed effects to the fact that the critical picture depicted a spider. Given this limitation, we cannot rule out the possibility that similar effects would be observed with other stimuli of negative emotional valence. Therefore, we have deliberately denoted the observed effects as due to negative valence, rather than due to the specific spider features of the image, and additional research is needed to determine the boundary conditions of the effects. For instance, would those memory advantages, which were observed in both groups, occur for NACs who rate the stimuli as negative as well as for NACs who do not? And would they be observed for other negative stimuli? Previous research on attentional biases suggests that this might be the case (Hansen & Hansen, 1988; Öhman et al., 2001). Moreover, would the effects, which were specific to the spider-fearfuls, also occur for other negative items, particularly other animals? Previous research indicates that this might be true for highly similar animals (e.g., beetles; see Becker & Rinck, 2004), but not for other animals such as snakes (Öhman et al., 2001). Thus, we expect that future research will show that the memory advantage for uncued spiders observed solely in spider-fearfuls is indeed due to the particular threat value that spider-fearfuls ascribe to spiders.

Second, although our findings are compatible with claims that fears and phobias in modern humans are strongly affected by evolutionary processes (e.g., see the "evolved fear module" proposed by Öhman & Mineka, 2001), the design of the current experiment is too limited to confirm this claim. In order to test this

hypothesis with regard to the two attentional bottlenecks, future experiments need to employ “modern” threats (e.g., weapons) in addition to evolutionary “old” ones such as spiders and snakes. If the effects observed here do not occur for modern threats, stronger evidence for an evolutionary basis of the observed memory advantages could be supplied.

Third, as we aimed to replicate the experimental design used by Wolfe et al. (2006), on each trial, participants were allowed to view the 4×4 matrix of images for 500 ms before the cueing procedure started. Possibly, some of the preferential processing of uncued spiders observed in the spider-fearfuls occurred during this initial phase, given the initial attentional bias toward threatening stimuli observed in spider-fearfuls (Rinck & Becker, in press). Therefore, future research should determine the relative role of this initial phase compared to the cueing phase itself.

Finally, as it is often the case, it would be advantageous to replicate the current study with a larger sample size and better statistical power. This would be helpful not only to test whether the current results may be replicated, but also to determine whether some of the weak interactions found here would either disappear or become statistically significant with more statistical power.

To summarize, the modified visual working memory paradigm employed here was successful in extending earlier experiments with emotionally neutral materials to the processing of negative materials. Moreover, the results add to the growing literature on cognitive biases in specific phobias, and they direct our attention to the “missing link” between attention and memory, namely, to the attentional bottleneck and to visual working memory. We expect that further research along these lines will prove to be a worthwhile enterprise.

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