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Visual working memory and threat monitoring: Spider fearfuls show disorder-specific change detection

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ABSTRACT

Previous studies of biased information processing in anxiety addressed biases of attention and memory, but little is known about the processes taking place between them: visual working memory (VWM) and monitoring of threat. We investigated these processes with a change detection paradigm. In Experiment 1, spider fearfuls (SF) and non-anxious controls (NAC) judged two subsequently presented displays as same or different. The displays consisted of several pictures, one of which could depict a spider. In Experiment 2, SF and NAC, both without snake fear, were tested with displays including either a spider or a snake image to determine the material-specificity of biased VWM. Both groups showed increased change detection for threat images. This effect was significantly stronger in SF, for spider images only, indicating a threat-specific VWM bias. Thus, contrary to the assumptions made by most cognitive models of anxiety, an explicit memory bias was found.

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Following cognitive theories of anxiety, preferential processing of threatening material is a key factor in the development of a disorder (e.g., Fox, Russo, & Dutton, 2002; Mathews & Mackintosh, 1998; Mogg & Bradley, 1998; Williams, Watts, MacLeod, & Mathews, 1997). Many of these models postulate a *vigilant-avoidant threat processing* pattern in anxious patients, involving a fast, automatic attentional selection of threat on the one hand, and a subsequent avoidance of prolonged attention and elaboration on the other. As a result, it is predicted that anxious individuals show an attentional bias, but no explicit memory bias for threatening material (Mogg & Bradley, 1998; Williams et al., 1997). The assumption of *vigilance* for threat information is empirically supported by studies consistently showing attentional bias for threat in anxious participants compared to non-anxious controls (for a review, see Mathews & MacLeod, 2005). In contrast, evidence for the *avoidance* of further processing of these stimuli is less consistent: most studies indeed fail to find a memory bias for threatening material in explicit memory tasks (for a review, see Coles & Heimberg, 2002). However, contrary to the predictions of cognitive models, some studies *do* report explicit memory biases in

anxiety (Russo, Fox, Bellinger, & Nguyen-van-Tam, 2001; Wilhelm, McNally, Baer, & Florin, 1996).

When reviewing these models as well as empirical bias research, it is striking that there is a focus on the two extremes of the information processing continuum: attention and long-term memory. In between, a gap remains, the bridging of which might bring us closer to determining the rubicon where anxiety-specific hypervigilance gives way to an avoidance of deeper processing (e.g., Williams et al., 1997): *visual working memory* (Baddeley, 2000). Studies investigating attentional biases merely require detection of and immediate reaction to a threatening stimulus without any deeper elaboration processes, and studies investigating memory mostly test for word lists after several minutes. That is, we have detailed knowledge about the moment a spider phobic detects a spider on the wall and of the moment when the spider has been removed for several minutes. But we do not know what happens in the meantime, although it seems plausible that a spider phobic, for instance, would find it relevant to monitor the speed and direction of movements of a spider present in the room, even while attending an important meeting. This monitoring relies on visual working memory.

So far, only very few studies investigated visual working memory (VWM) biases, reporting enhanced immediate memory for the spatial position of spiders in fearfuls compared to healthy controls (Reinecke, Becker, & Rinck, 2009; Reinecke, Rinck, & Becker, 2006). However, while the paradigm used in these studies

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assesses how fearfuls process information about the location of spiders in static displays, it does not allow conclusions about the monitoring of the spider's change of that position. This type of monitoring seems particularly relevant in phobia, though: research shows that the unpredictability of threatening stimuli contributes significantly to phobic fear (Merckelbach, van den Hout, Jansen, & van der Molen, 1988). Animals' ability to crawl, jump, or disappear into your trouser leg makes them clearly unpredictable. Indeed, three out of four animal phobics experience the animal's movement as distressing (McNally & Steketee, 1988). One would therefore assume that monitoring of the phobic stimulus is highly essential in controlling the fear.

Cognitive psychology has generated excellent paradigms to investigate general monitoring, mainly in the field of change blindness research. This phenomenon is a fascinating example of the limitations of human information processing, showing that many participants are unable to detect the replacement of a person they are talking to (Simons & Levin, 1998) or the appearance of a gorilla during a basketball game (Simons & Chabris, 1999). But would change blindness occur in a spider phobic in view of a spider threatening to disappear into his trouser leg, or in a person with an obsessive–compulsive form of anxiety in face of another person swapping drinking glasses? So far, only very few studies addressed the relationship between psychiatric disorders and change detection for disorder-relevant stimuli (e.g., Jones, Jones, Smith, & Copley, 2003; Mayer, Muris, Vogel, Nojoredjo, & Merckelbach, 2005). For instance, Mayer et al. (2005) asked observers to view visual real-life scenes. On some trials, a spider vs. a neutral item gradually appeared within the scene and participants had to indicate at the end of the trial whether a new item was added or not. Spider fearfuls performed better in detecting spider-related changes, that is, an appearing spider, than non-anxious participants.

To evaluate the theoretical relevance of these results, it is important to differentiate between two types of change detection paradigms. On the one hand, paradigms as the one used by Mayer et al. (2005) address the general monitoring of spatial scenes and attention for threat appearing within these scenes. The same is true for flicker paradigms (e.g., Jones et al., 2003), where one scene and the same scene including one altered object switch back and forth until the change is recognized. Thus, the Mayer et al. (2005) results add an interesting aspect to the vast literature on attentional bias in anxiety. In contrast, the change detection task introduced by Luck & Vogel (1997) has been shown to directly tackle visual working memory. However, it has not been adapted to emotional material yet. In the original task, participants were presented a study display of simple, coloured dots for only 100 ms in each trial. After a short delay, a test display was presented. This was either exactly the same as the study display, or contained a colour change in one of the dots. The number of dots was varied, and participants indicated whether the two displays were identical or different. It was also ensured that only working memory resources were employed by giving participants a verbal memory load (a triple-digit number) at the beginning of each trial for later recall. As the two displays are only presented once for comparison, volunteers are required to efficiently employ visual working memory. Their performance in change detection abruptly dropped with set sizes larger than four dots, leading the authors to conclude that the storage size of visual working memory is four items (see also Wolfe, Reinecke, & Brawn, 2006). Considering these strict resource limitations, would a spider item be one of the four items selected to be monitored and held in working memory by a spider phobic?

In the present study, we aimed at shedding more light on working memory bias in anxiety, particularly on its role in threat monitoring. We therefore adapted the change detection task introduced by Luck and Vogel (1997) to clinically relevant material.

In Experiment 1, we tested whether spider fearfuls and non-fearful individuals would differ in detecting changes to spider images. In Experiment 2, we tested whether any group differences found in Experiment 1 were fear-specific and would only occur for the feared object, or for all threatening objects. For instance, Ohman, Flykt, and Esteves (2001) found that all participants showed faster detection of evolutionary relevant materials such as snakes and spiders, and that this effect was enhanced in snake phobics and spider phobics, respectively. To test whether the same would be true for VWM biases, we assessed the performance in detecting changes applied to snake images in spider fearfuls and non-anxious controls, all of them without fear of snakes.

Experiment 1: Applying a classical VWM task to fear of spiders

Based on the VWM task introduced by Luck and Vogel (1997), we measured participants' accuracy in judging two displays as same or different, depending on the valence of the displays. By including a spider picture, we varied the external threat value of the material, and by comparing a spider fearful group to a group of non-anxious controls, we varied the individual threat value of the spider item. We expected enhanced memory for spider changes in the spider fearful group compared to non-anxious controls. However, it is important to differentiate between two trial types. First, a spider can *appear*, meaning that it is not presented in the study (first) display, but in the test (second) display. This trial type is similar to a phobic scanning the environment for threatening objects and detecting them at some point (“*Oh dear, there is a huge spider, this hasn't been there before!*”). In a second trial type, however, the spider can *disappear*, meaning that it had been presented in the study display, but not in the test display anymore. This trial type is comparable to a phobic detecting the threatening object and then monitoring it over a period of time, for example to check whether it had moved (“*It's gone, oh no, where is it?*”). This requires a WM representation of the spider, and we are especially interested in group differences in this condition. Luck and Vogel's (1997) research showed that humans' VWM is capable of holding at most 4 simple items. Therefore, they are forced to selectively and – due to the very short presentation time – reflexively encode a subset of items from the study display into VWM. Based on prior studies of attentional biases, we predict that for spider fearfuls, the spider item should be one of these four items if it is present, even with a presentation time of only 100 ms. Attentional bias research not only suggests that phobics show faster detection of threatening stimuli, but that phobics also exhibit stronger distraction from other stimuli by the threatening stimulus (e.g., Rinck, Reinecke, Ellwart, Heuer, & Becker, 2005). Therefore, we predicted that the spider fearfuls' improved VWM performance for spider changes will be accompanied by poorer VWM performance for neutral changes in displays that contain a spider item.

Methods

Participants

Twenty spider fearfuls (SF) and 20 non-anxious controls (NAC) without any animal-oriented fears were tested. Pre-screening took place in lectures at Dresden University of Technology using the German *Spider Anxiety Screening* (SAS; Rinck et al., 2002). Students with scores lower than 5 (minimum 0) or higher than 14 (maximum 18) were invited to further test their suitability for the study. They were then given the *Fear of Spiders Questionnaire* (FSQ, range 0–108; Szymanski & O'Donohue, 1995; German version: Rinck et al., 2002) and were required to show a maximum score of 10 to be considered as NAC or a minimum score of 30 to be eligible as SF. In addition, they all had to score lower than 14 on the *Inventory to Diagnose Depression*

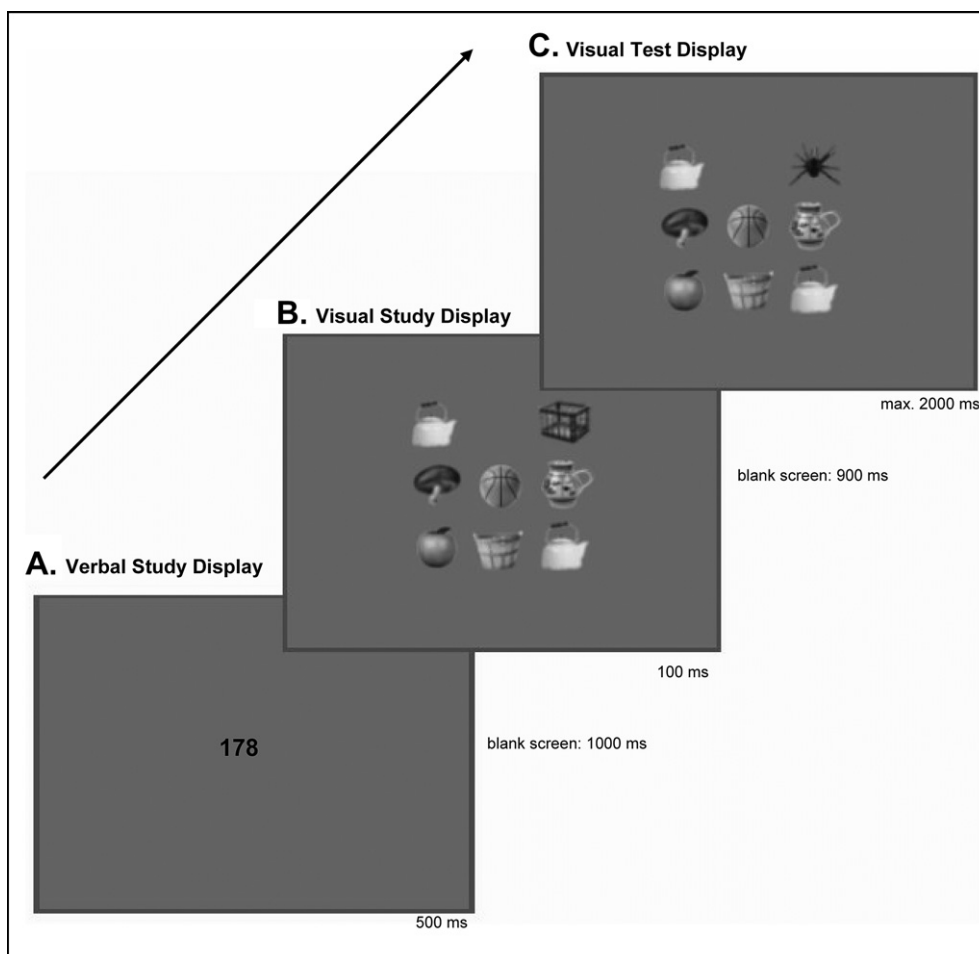


Fig. 1. Sample experimental trial. Participants view a triple-digit number first, then a study display, and afterwards a test display. Participants' task is to memorize the digits via verbal WM and to judge the two picture displays as same or different. The figure shows a "spider appears" trial. Note: Actual stimuli were in colour.

(IDD, range 0–72; Zimmermann, Coryell, Wilson, & Corenthal, 1986; German version: Kühner, 1997). Moreover, DSM-IV criteria for spider phobia were checked using the *International Diagnosis Checklist for DSM-IV* (ICDL; Hiller, Zaudig, & Mombour, 1997). Participants were required to fulfil all criteria expect criterion E, which defines significant impairment in everyday life. Considering the ease of avoiding threatening spiders in Northern Europe, not fulfilling this criterion is comprehensible and does not affect the questions of interest. Further exclusion criteria were alcohol or drug abuse, current attention-affecting medication (checked with an interview), and psychosis (checked with the *Anxiety Disorders Interview Schedule for DSM-IV* (ADIS; DiNardo, Brown, & Barlow, 1994). The SF group and the NAC group were matched with regard to age, gender, and educational level. On average, the 16 female and 4 male NAC were 21.7 years old ($SD = 2.3$), the 19 female and 1 male SF had a mean age of 21.2 years ($SD = 2.7$). All participants gave informed consent. In return for their participation, they received course credit or a payment of 5 EUR.

Materials and apparatus

The experiment was operated by MATLAB software using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Experimental materials were presented on a gray background on a 17" monitor with a resolution of 1024×768 pixels. Stimuli for the verbal WM load task were randomly chosen black printed triple-digit numbers of the font size 25 displayed in the centre of the screen

(see Fig. 1A). Stimuli for the VWM task were 36 colour pictures with an approximate side length of 115 pixels: one fear-relevant image (spider) and 35 fear-irrelevant images (e.g., butterfly, apple, fan).¹

Procedure

Participants were presented two picture displays in a row to decide whether they involved the same pictures, or whether one of the pictures was different. While most pictures were neutral or positive, one of them could show a spider. A sample trial is shown in Fig. 1. Each experimental trial started with the presentation of a black, centred fixation cross for 500 ms. In line with the original Luck & Vogel (1997) design, a triple-digit number was shown afterwards for 500 ms to be memorized (digit-by-digit) throughout the trial and reported at the end. By adding such a procedure, the capacity of the verbal WM component is stressed and therefore cannot support the encoding of the picture displays (see Baddeley, 2000). Thus, we can assume that picture change detection indeed relies on the visual WM component as intended. After the presentation of a blank screen containing a fixation cross for 1000 ms,

¹ Valence and arousal ratings for these images were assessed in an earlier study (Reinecke et al., 2009a). While both groups categorized the spider image as arousing (with higher ratings in fearfuls), controls rated the spider image as neutrally valenced and fearfuls as negative. The remaining 35 non-critical images were all judged as neutral (e.g., backpack, carton) or positive (e.g., blossom, puppy) and not arousing.

a picture study display was presented for 100 ms, containing either four, six, or eight images. The variation in picture set size was solely included to keep picture set-ups diversified throughout the experiment and therefore reduce the probability of controlled encoding strategies. Although change detection performance generally decreased with increasing set size, this factor did not significantly interact with any of the other factors. Detailed statistical reports can be requested from the first author, but are not reported here due to space limitations. In each trial, 4, 6, or 8 pictures were randomly selected from the pool of 36 pictures and were distributed randomly over the nine possible locations of an invisible 3×3 grid. Whether one of these pictures was the spider was likewise randomly controlled by the experimental software. After presenting another blank screen for 900 ms, a test display was provided for up to 2000 ms. This display consisted of the same number of items as the study display, but one item's identity had changed in half of the trials. Participants were instructed to decide whether the two subsequently presented picture displays were identical or not by pressing either the *Same* or the *Different* response key, and to then recall the initially displayed triple-digit number (digit-by-digit) by typing it into the number pad. Written feedback was given promptly after each picture and number response, respectively. A sample trial with a set size of 8 is shown in Fig. 1. On each trial, set size, picture set and the existence of a change were randomly determined by the experimental program. After the experiment, participants completed the STAI-Trait questionnaire (STAI-T; Laux, Glanzmann, Schaffner, & Spielberger, 1981). Finally, participants were debriefed and SF were informed about treatment possibilities concerning spider phobia. The experiment took about 35 min, a complete session lasted about 60 min.

Design

The experiment was based on an incomplete $2 \times 2 \times 2 \times 2$ factorial design with the within-subjects factors *study display* (neutral, spider), *test display* (neutral, spider), *change type* (same, different) and the between-subjects factor *group* (SF, NAC), see Table 2. The reason for the incompleteness is that when one combines the factors *study display*, *test display*, and *change type*, some combinations are inevitably impossible: For instance, when the study display includes a spider, and the test display does not, a change *must* have occurred. The incompleteness of the design does not pose a problem, however, because we tested specific predictions for which an analysis of the complete data set would be inappropriate. To avoid response biases that could arise from a higher probability of one of the two response categories (same, different) or one of the two study displays (spider, neutral) due to the incomplete design, it was required to balance the probability of the correct answer being "same" vs. "different", and the probability of the study display including a spider vs. no spider. In order to set these probabilities to 50%, some factorial combinations were presented 10 times, others 20 times.² Participants performed 240 experimental trials, preceded by 8 practice trials. For each experimental condition, the participants' mean accuracy in judging the two visual displays as same or different was calculated, but only for trials with a correct report of the verbal WM digit. This was done in line with the original procedure described by Luck & Vogel (1997) to ensure that the change detection accuracy indeed only traces back to visual working memory, without any support from verbal resources. In the analyses, interactions including the factor *group* were of main interest, because they correspond to fear-specific effects.

² The combinations depicted in cells A and E in Table 2 were presented 20 times, those of cells B, C, D, and F 10 times.

Results

Questionnaires

The mean scores for the two groups of participants regarding age and questionnaires are shown in Table 1. Depression scores (IDD) and trait anxiety scores (STAI-T) fell within the normal range, with SF showing slightly, but significantly higher scores than NAC on the IDD and the STAI-T.

Experimental task

Prior to the statistical data analyses, practice trials and trials with an incorrect triple-digit number response were discarded from the data set. The latter occurred in only 8% of all trials. Table 2A shows the calculated mean accuracy values in judging the study and the test picture display as same or different. To test the specific hypotheses stated above, we computed several specific analyses of the relevant experimental conditions. For ease of traceability, the cells of the complete data depiction in Table 2A are labeled from A to F. We refer to these labels when explaining our analyses.

Hypothesis 1: Memory enhancement for spider displays

To test whether the spider item receives a favoured role in VWM and whether this is the case for both groups or only for the SF group, we compared the change detection accuracies of the two groups in spider trials vs. neutral trials. For the *neutral change* condition, we considered mean accuracy in detecting an intermittent change when both displays were neutral (cell B, see Table 2A). A mean accuracy score for *spider change trials* was calculated by averaging the means of trials in which the study display was neutral but a spider appeared in the test display (cell D), and trials in which the study display showed a spider that disappeared when switching to the test display (cell F). These values were subjected to a 2×2 ANOVA including the between-subjects factor *group* (NAC, SF) and the within-subjects factor *threat* (neutral trials, spider trials). In both groups, change detection was better in spider trials than in neutral trials, $F(1,38) = 26.61, p < .001, \eta^2 = .41$. However, this effect was stronger in SF, as indicated by a significant group \times threat interaction, $F(1,38) = 4.65, p < .05, \eta^2 = .11$. This was confirmed by additional paired *t*-tests assessing differences in change detection between neutral versus spider trials, separately for each group, SF: $t(19) = 4.62, p < .001, d = 1.15$, NAC: $t(19) = 2.46, p = .024, d = .52$, as well as independent-samples *t*-tests separately for each threat condition, neutral: $t(38) = 0.21, p = .834, d = .07$, spider: $t(38) = 3.13, p = .003, d = 1.05$.

To further explore whether threat change detection depends on whether the spider *appears* versus *disappears* over the presentation of two displays, we ran an additional, more detailed analysis: We compared mean change detection accuracy for neutral changes (cell B), versus performance in trials with a spider item appearing in the test display (cell C), versus change detection in trials with

Table 1

Questionnaire scores (means, standard deviations, significance of *t*-tests) of the participants in Experiment 1 ($df = 38$) and Experiment 2 ($df = 42$).

	Experiment 1			Experiment 2		
	SF	NAC	<i>t</i> -test	SF	NAC	<i>t</i> -test
age	21.2 (2.7)	21.7 (2.3)	n.s.	21.7 (2.8)	22.6 (4.3)	n.s.
SAS	18.2 (4.5)	1.9 (2.9)	.001	18.0 (3.2)	1.6 (1.4)	.001
FSQ	61.5 (21.5)	2.0 (2.6)	.001	61.6 (17.8)	2.1 (2.4)	.001
IDD	6.7 (4.1)	3.7 (3.4)	.05	5.3 (3.1)	3.5 (3.3)	n.s.
STAI-T	41.1 (7.9)	34.8 (7.7)	.05	40.4 (8.6)	35.7 (5.9)	.05
SCANS				2.7 (2.0)	1.9 (1.8)	n.s.
SNAQ				5.4 (2.8)	4.0 (3.3)	n.s.

Table 2
Mean accuracy (and standard deviations) in judging the test display as same or different in Experiment 1 and Experiment 2. Threat changes in threat displays are in boldface, neutral changes in threat displays are italicized, neutral baseline conditions are not highlighted. For ease of communication, the cells are labeled with uppercase letters A to F to be referred to in the text.

Group	NAC				SF			
	Neutral		Spider		Neutral		Spider	
Study display	Neutral	Spider	Neutral	Spider	Neutral	Spider	Neutral	Spider
<i>Experiment 1</i>								
SPIDER								
Same	.82 ^A (.08)	–	–	.81 ^E (.05)	.86 ^A (.06)	–	–	.83 ^E (.09)
Different	.63 ^B (.12)	.70^C (.16)	.70^D (.08)	.62 ^F (.09)	.64 ^B (.17)	.76^C (.16)	.83^D (.09)	.66 ^F (.17)
<i>Experiment 2</i>								
SPIDER								
Same	.85 ^A (.07)	–	–	.88 ^E (.07)	.89 ^A (.06)	–	–	.87 ^E (.07)
Different	.56 ^B (.14)	.79^C (.16)	.83^D (.14)	.54 ^F (.15)	.55 ^B (.15)	.90^C (.09)	.94^D (.06)	.51 ^F (.15)
SNAKE								
Same	.87 ^A (.07)	–	–	.88 ^E (.06)	.86 ^A (.09)	–	–	.85 ^E (.09)
Different	.55 ^B (.11)	.76^C (.03)	.82^D (.14)	.56 ^F (.15)	.62 ^B (.14)	.81^C (.14)	.84^D (.11)	.59 ^F (.20)

a spider item disappearing in the test display after having been presented in the study display (cell D). These values were subjected to a 2 × 3 ANOVA involving the between-subjects factor *group* (NAC, SF) and the within-subjects factor *change condition* (neutral, spider appears, spider disappears). The results are shown in Fig. 2. The analysis revealed a significant overall effect of condition on change detection performance, *change condition*: $F(2,76) = 14.22$, $p < .001$, $\eta^2 = .27$, which was significantly larger in SF, *group* × *change condition*: $F(2,76) = 3.22$, $p < .05$, $\eta^2 = .08$. To further investigate these effects, additional one-way ANOVAs for the factor *change condition* were run, separately for the two groups. The effect of condition was highly significant in SF, $F(2,38) = 13.14$, $p < .001$, $\eta^2 = .41$, but only marginally significant in NAC, $F(2,38) = 2.68$, $p = .082$, $\eta^2 = .12$. Paired *t*-tests comparing accuracy between the three change conditions for SF only showed that they performed significantly better in the two spider change conditions compared to the neutral condition, both $t(19) > 3.55$, both $p < .01$, both $d > .73$. There was only a non-significant trend for enhanced report of spider changes when the spider disappeared over displays compared to when it appeared, $t(19) = 1.83$, $p = .083$, $d = .54$. In addition, we compared change detection differences between the two groups, separately for each condition, with independent-samples *t*-tests. SF showed significantly better change detection

performance than NAC for disappearing spiders, $t(38) = 4.80$, $p < .000$, $d = 1.64$. The groups did not differ in detecting a neutral change, $t(38) = 0.21$, $p = .834$, $d = .07$, or an appearing spider, $t(38) = 1.37$, $p = .179$, $d = .44$.

Hypothesis 2: Visual memory distraction in spider displays

Because the prior analyses revealed enhanced memory for spiders, we also tested whether this advantage came at the expense of change detection regarding neutral items. Therefore, we compared change detection accuracy for neutral items in displays without spiders (cell A) to change detection accuracy for neutral items in displays including a spider (cell F). These means were subjected to a 2 × 2 ANOVA with the between-subjects factor *group* and the within-subjects factor *spider presence* (neutral trials, spider trials). There were no costs in any of the groups in noticing a neutral change when a spider was present, *presence*: $F(1,38) < 1$, $p = .935$, $\eta^2 = .00$, *group*: $F(1,38) < 1$, $p = .498$, $\eta^2 = .01$, *presence* × *group*: $F(1,38) < 1$, $p = .519$, $\eta^2 = .01$. Thus, change detection regarding neutral items was not affected by the presence of a spider item in the display, despite the spider's VWM advantage.

Discussion

In both groups, change detection was enhanced for spiders compared to neutral items. The two groups did not differ from each other in change detection performance regarding neutral trials and spider appears trials. However, SF were significantly better in reporting changes in which a spider item of the study display was replaced by a neutral item (*spider disappears*). These results suggest that both fearfuls and non-fearfuls show a similar ability to scan a test display for spider items, and to detect a new spider item and make the decision that it had not been presented before. In contrast, monitoring threat seems to be an ability specifically developed in fearfuls: SF show an additional advantage in reporting a disappearing spider compared to NAC. Therefore, the data do indeed imply fear-specific biases of VWM and monitoring, because the accurate report of the disappearance rather than appearance of a spider reflects these processes. Interestingly, these memory advantages for spiders were not related to costs in VWM. That is, all participants performed comparably well in noticing a change made to a neutral item, no matter whether there was a spider item visible within the displays or not.

Experiment 2: VWM for spiders and snakes in spider fearfuls

Experiment 1 demonstrated that spider fearfuls show enhanced VWM for spider displays compared to non-anxious controls. In

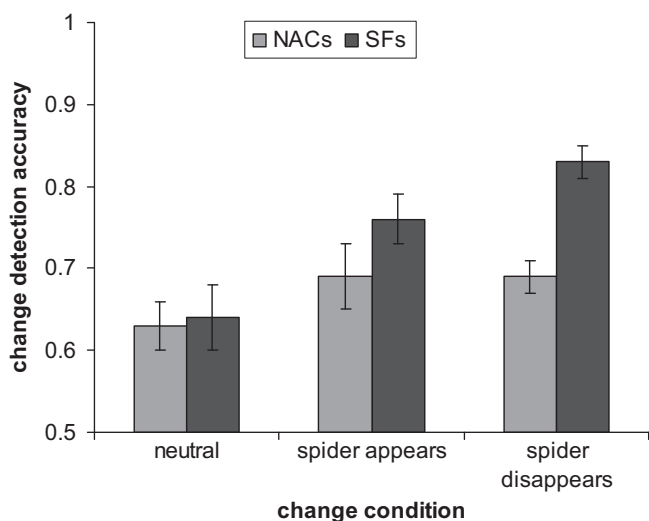


Fig. 2. Memory enhancement for spider images. Mean percent correct in change detection in Experiment 1, separately for the three change conditions and the two groups. Error bars show the standard error of the mean.

Experiment 2, we tested whether this advantage is not only fear-specific, but also *threat-specific*. Do spider fearfuls show improved memory performance only for the stimuli they are afraid of, namely, spiders? Or does the memory advantage occur for all kinds of prepared-threatening animals (Seligman, 1971)? So far, only a few studies of attentional bias employed materials of varying individual fear levels (e.g., Ohman et al., 2001). However, clarification of the specificity of processing biases is essential for the formulation of cognitive theories of anxiety, as well as for therapy concepts. In Experiment 2, a group of spider fearfuls was compared to a group of non-anxious controls, while *both* groups were without fear of snake. We repeated the task used in Experiment 1 once with a spider as the critical stimulus, and once with a snake. The spider block served to replicate the spider-related results observed in Experiment 1, and the snake block served to determine VWM performance for snakes. The following hypotheses were tested: (1) Both groups show enhanced WM performance for spiders and snakes compared to neutral items. (2) The enhanced performance for spiders is especially pronounced in SF. (3) The two groups do not differ regarding WM enhancement for snakes.

Methods

Participants

Twenty-two spider fearfuls (SF) and 22 non-anxious controls (NAC) without any animal-oriented fears were tested. None of them had participated in Experiment 1. The recruitment and selection procedure was identical to that of Experiment 1, except for the addition of the *Snake Anxiety Screening* (SCANS; Reinecke, Hoyer, Becker, & Rinck, 2009) and the *Snake Anxiety Questionnaire* (SNAQ, Klorman, Hastings, Weerts, Melamed, & Lang, 1974; Reinecke, Hoyer, et al., 2009). Only candidates who had a maximum SCANS score of 4 (range 0–18) and a maximum SNAQ score of 10 (range 0–30) were allowed to participate in the experiment. On average, the 18 female and 4 male members of the NAC group were 22.6 years old ($SD = 4.3$), the 18 female and 4 male participants of the SF group had a mean age of 21.7 ($SD = 2.8$).

Materials, apparatus, and procedure

The apparatus and experimental stimuli were identical to those of Experiment 1, except for the addition of a second critical stimulus, namely, a snake image.³ The snake was coloured black, and its picture had the same high contrast as the spider picture. Participants completed two different blocks of trials: In one block, the spider image from Experiment 1 was the critical item. In the other block, the new snake image was used. The order of the two blocks was counterbalanced across participants. A complete session took about 90 min.

Design

The design was nearly the same as in Experiment 1, with the only difference that the two-level factor *critical stimulus* (spider, snake) was included. Thus, the incomplete $2 \times 2 \times 2 \times 2$ factorial design included the between-subjects factor *group* (SF, NAC) and the within-subjects factors *critical stimulus* (spider, snake), *study display* (neutral, threat), *test display* (neutral, threat) and *change type* (same, different). In total, 480 experimental trials were run.

³ In an earlier study (Reinecke et al., 2009a), both spider fearfuls and controls, both without snake anxiety, rated the snake image as arousing and neutrally valenced, without any differences between the groups.

Results

Questionnaires

The mean scores, standard deviations, and significances of *t*-tests of age and questionnaires for both groups of participants are depicted in Table 1. The two groups were not different from each other regarding depression (IDD) and snake anxiety (SCANS, SNAQ). However, the SF had significantly higher trait anxiety scores (STAI-T).

Experimental task

Data aggregation and calculation were identical to Experiment 1. Table 2B shows mean accuracies in judging the two displays as same or different for each possible combination of *study display*, *test display*, and *change type*, separated for the spider versus snake block. To test whether the enhancement effects observed in Experiment 1 are threat-specific for SF, we compared group differences in change detection in the spider block to group effects in the snake block. We compared mean change detection accuracy for neutral changes (cell B) versus spider/snake-appearing changes (cell C), versus spider/snake-disappearing changes (cell D). A three-way ANOVA was run, including the between-subjects factor *group* (SF, NAC) and the within-subjects factors *stimulus* (spider, snake) and *change condition* (neutral, spider/snake appears, spider/snake disappears) see Figure 3. The significant main effect of condition, $F(2,84) = 142.29$, $p < .001$, $\eta^2 = .77$, indicated that both groups in general performed better in detecting threat changes than neutral changes. The significant *stimulus* \times *group* \times *change condition* interaction, $F(2,84) = 4.48$, $p = .014$, $\eta^2 = .10$, however, suggested that while SF showed enhanced detection of spider changes compared to NAC, they showed no such advantage regarding snake trials. To further explore these effects, additional *group* \times *change condition* ANOVAs were run, separately for each stimulus type.

Spider block

The participants exhibited higher accuracy in detecting spider changes than neutral changes, $F(2,84) = 119.70$, $p < .001$, $\eta^2 = .74$, and this advantage was larger in SF, $F(2,84) = 4.77$, $p = .011$, $\eta^2 = .10$. This finding was confirmed by additional one-way ANOVAs and paired-samples *t*-tests comparing accuracy between the three change conditions, separately for the two groups. Both groups showed higher change detection performance for *spider appears* trials and *spider disappears* trials compared to neutral trials, both $F(2,42) > 40.50$, both $p < .001$, both $\eta^2 > .66$, all $t(21) > 7.02$, all $p < .001$, all $d > 1.53$. However, only SF showed an additional advantage for disappearing spiders compared to appearing spiders, SF: $t(21) = 2.17$, $p = .042$, $d = .52$, NAC: $t(21) = 1.68$, $p = .109$, $d = .27$. In addition, we compared change detection differences between the two groups, separately for each condition, with independent-samples *t*-tests. As expected, SF showed significantly better change detection performance than NAC for both types of spider changes, both $t(42) > 2.82$, both $p < .01$, both $d > .85$, but not for neutral changes, $t(42) = 0.32$, $p = .751$, $d = .07$.

Snake block

Both groups performed better in detecting snake changes than non-snake changes, $F(2,84) = 52.81$, $p < .001$, $\eta^2 = .56$, without any group differences, *group*: $F(1,42) = 2.71$, $p = .107$, $\eta^2 = .06$, *change condition* \times *group*: $F(2,84) = 0.54$, $p = .587$, $\eta^2 = .01$. This result was confirmed by additional one-way ANOVAs and paired-samples *t*-tests between neutral versus snake change conditions, computed separately for each group, both $F(2,42) > 20.47$, both $p < .001$, both $\eta^2 > .49$, neutral-appear: both $t(21) > 5.35$, both

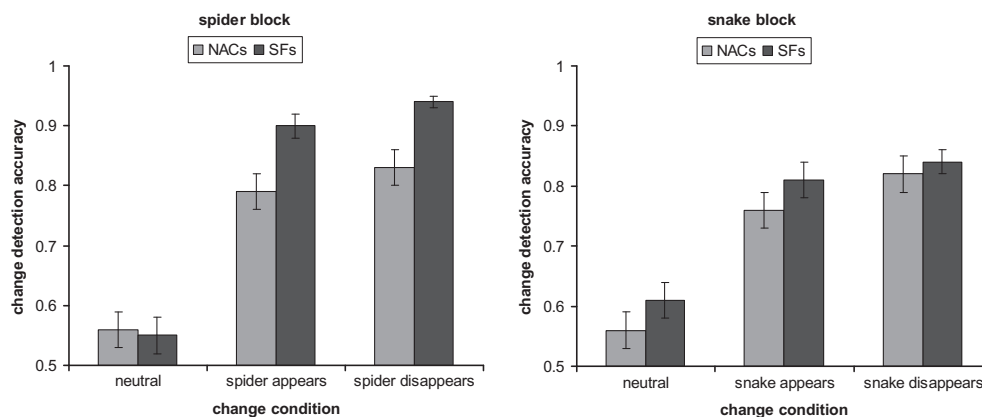


Fig. 3. Fear-specific memory enhancement. Mean percent correct in change detection depending on group, change condition, and critical stimulus in Experiment 2. Left: Accuracy in the spider block. Right: Accuracy in the snake block. Error bars show the standard error of the mean.

$p < .001$, both $d > 1.36$, neutral-disappear: both $t(21) > 5.16$, both $p < .001$, both $d > 1.75$.

Spider versus snake block

The previous results indicate that SF were better than NAC at detecting spider changes, but not at detecting snake changes. An additional set of analyses was conducted to determine whether SF, but not NAC, would also detect spider changes *better* than snake changes. We computed a 2-way ANOVA including the factors *group* and *threat item* (spider, snake). This analysis included all trials for which a change was applied to a spider or a snake, respectively (averaged cells C and D, see Table 2B). The analysis indicated that indeed only SF showed better performance for spiders than for snakes, $F(1,42) = 4.41$, $p < .05$, $\eta^2 = .10$. This was confirmed by additional paired-samples t -tests comparing spider change detection accuracy versus snake change detection, separately for each group, SF: $t(21) = 4.04$, $p = .001$, $d = 1.21$, NAC: $t(21) = 0.60$, $p = .555$, $d = .15$.

Discussion

Both groups were better at detecting threat-related changes than neutral changes. Independently of whether the critical stimulus was a spider or a snake, both SF and NAC showed higher change detection accuracy in *appear trials* and *disappear trials*, compared to neutral trials. While there were no group differences at all in the snake condition, SF showed superior performance compared to NAC in both spider change conditions. Fearfuls even exhibited an additional *threat monitoring* ability, reflected in reporting more accurately that a spider had disappeared versus that a spider had appeared in the test display. Comparing the two stimulus conditions, SF were significantly better in change detection regarding spiders compared to reporting a snake change. Thus, pictures of snakes were likewise special for SF and NAC. Pictures of spiders were also special for both groups, but especially so for SF, replicating the results of Experiment 1.

General discussion

Previous research has generated numerous studies investigating attentional bias and memory bias in anxiety (for a review, see Williams et al., 1997). However, only very little is known about the important processes taking place in between these two levels of information processing: visual working memory and monitoring of threat. This study aimed at adding knowledge to this scarcely investigated process by investigating biased change detection in anxiety.

Experiment 1 revealed that the emotionality of an item has a significant impact on VWM. Overall, both groups performed better in change detection regarding spiders compared to neutral items. The two groups' change detection accuracy was similar in neutral trials and in trials in which a spider appeared in the test display after having not been presented in the study display. The appearance of this general emotion effect even in non-anxious participants is in line with earlier results on VWM biases (Reinecke, Becker, et al., 2009; Reinecke et al., 2006). However, SF performed significantly better than NAC in detecting that a spider disappeared. The advantage in the SF group shows that they favour the processing of spider items in VWM over other items, as this condition particularly requires the selection of the spider item for short-term storage. This supports the idea that fearfuls monitor a threatening stimulus, even after they have detected it, at least over a short period of time. Interestingly, none of the memory advantages for spiders came at the expense of memory costs for other items.

Experiment 2 showed a memory advantage for spider and snake displays compared to neutral displays for both SF and NAC. Only in the spider block, SF additionally revealed change detection advantages in both threat trial conditions: as in Experiment 1, they were better in recognizing when a spider disappeared, and here they were also better at detecting an appearing spider. Moreover, spider fearfuls were better at detecting disappearing spiders than appearing ones. In addition, their memory performance for spider displays was significantly better than their performance for snakes, while no such difference occurred in NAC.

In sum, the most striking group differences were indeed observed in the threat VWM condition in which a spider was presented in the first, but not in the second display anymore. This condition represents the phobics' tendency to monitor the movements of a spider, even if only to adjust the distance between the animal and themselves to stay in control of their fear. It also nicely resembles the moment when the outcome of the monitoring process is that the threatening stimulus has disappeared and, therefore, becomes uncontrollable. Despite the very short presentation of the study display for only 100 ms, we found VWM biases in favour of threat items in both groups, and to a stronger degree in fearfuls. This highly restricted presentation time does not allow for strategic selection processes, especially as verbal working memory resources were blocked. Instead, selection of VWM material can only have taken place in an automatic, reflexive way. Since attention is the prerequisite for an item to be stored in VWM (Cowan, 1995; Sperling, 1967), we may assume that the memory biases found here are based on fear-related attentional biases that allow for a quick and automatic selection of threat items. This

interpretation would be in line with studies showing attentional biases for threatening animals in fearfuls and non-fearfuls, but to a stronger degree in fearfuls (e.g., Ohman et al., 2001). Moreover, this observation also matches the predictions of cognitive models of anxiety, assuming attentional preference for threat due to increased vigilance (e.g. Eysenck, 1992; Mathews & Mackintosh, 1998; Mogg & Bradley, 1998; Williams et al., 1997).

Our data show that this attentional bias results in the threat items being transferred into VWM and monitored over time. Unfortunately, current cognitive models of anxiety make no explicit predictions about biased information processing at the level of working memory at all. Most of these models assume an avoidance of prolonged processing of threatening material in anxiety once it has been detected, and therefore speak against the existence of explicit memory biases (Mogg & Bradley, 1998; Williams et al., 1997). However, this is in contrast with the results observed here, as we found VWM bias despite explicit, non-incidental stimulus encoding. Nevertheless, some more recent models are able to explain the results reported here, as they do predict explicit memory biases as long as the elaboration takes place in a perceptual rather than conceptual way (e.g., Fox et al., 2002; Mathews & Mackintosh, 1998). Considering the very short study display presentation time and the verbal load task participants were performing while comparing visual displays, the working memory task used was clearly tapping into perceptual processing resources. All in all, our data indicate that the presumed “cognitive avoidance” (e.g., Mogg & Bradley, 1998; Williams et al., 1997) does not only occur beyond attention, but also beyond working memory. When asking when anxiety-specific vigilance gives way to avoidance when dealing with threat material, the data presented here surely are not sufficient to give an exact answer. However, they are supporting the idea that this point does not seem to be at the level of attention or VWM.

Interestingly, the fear-specific memory advantages for spiders were not accompanied by fear-specific costs in VWM. At first glance, the lack of distraction effects seems to run counter to empirical results of attentional bias research, which often demonstrated distraction of attention by threatening stimuli in SF in visual search tasks (e.g., Rinck et al., 2005). Comparing visual search studies of attentional biases to the experiments presented here, we can determine one very prominent difference: experiments investigating distraction of attention without externally guiding the observer's attention typically use numerous pictures of the feared stimulus category as distractors (e.g., Rinck et al., 2005), whereas we presented only a single spider image.

Some limitations of the current study also need to be discussed. First, both groups showed enhanced memory for spider displays compared to neutral displays, although one of the groups did not fear spiders at all. Moreover, in Experiment 2, both groups, although without fear of snakes, showed enhanced change detection performance for snake displays. On the one hand, these observations might suggest that evolutionary relevant stimuli are not only preferably attended to (e.g., Ohman et al., 2001), but are also preferably stored in VWM. This would be in line with the theory of preparedness, implying that humans are predisposed to be alert of situations and animals that threatened survival (Seligman, 1971). On the other hand, it is possible that the enhancement would be observable with all kinds of negative or emotional material. This study was not designed to draw final conclusions regarding the impact of evolutionary relevance on VWM, but it would be a worthwhile extension of the current research to repeat the task with a common neutral or positive object or modern threat items, as for instance a hand grenade.

One might also wonder whether the psychophysical salience of the spider and snake pictures may account for the memory advantages observed in both groups. After all, both pictures had a distinctive

pattern and colour, and they depicted animals while most other images depicted non-living objects. However, this potential explanation was already tested and ruled out by Reinecke et al. (2006) and Reinecke, Becker, et al., (2009). In these studies, memory for the spider image was compared to memory for a butterfly image, because it was also dark and characteristic in shape, and also depicted an animal. The results showed a strong advantage for spider pictures over the butterfly images, indicating that the enhancement effects found for spiders (and probably also snakes) cannot be merely attributed to psychophysical salience effects.

However, one might argue that some strategic processes might have influenced the threat results observed in both groups, considering that spider and snake images were presented more often than non-threat items. It cannot be fully ruled out that participants developed a threat monitoring strategy that fuelled into the findings of higher memory accuracy for threat items compared to neutral items. Nevertheless, such a strategy would not account for differences between groups reported here, as both groups have been exposed to the same number of repetitions of the threat images.

In addition, the current data do not allow conclusions about whether we would also find biased working memory for disorder-specific material in other anxiety disorders, as for instance social phobia or generalised anxiety disorder. It is possible that monitoring is restricted to specific animal phobias only, as it seems particularly relevant to keep control over the situation. However, safety strategies and dysfunctional control mechanisms are relevant in all anxiety disorders in some specific way. Therefore it would be very worthwhile to investigate whether the same processes are measurable in other forms of anxiety.

In sum, the present study adds to our understanding of cognitive bias in anxiety in that it highlights visual working memory for threat. So far, VWM has rarely been investigated, and it has not found its way into cognitive models of anxiety yet. We were able to show that biased VWM and threat monitoring play a role in specific anxiety. This finding challenges current models which assume a very early avoidance of explicit threat processing.

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