Interpreting and responding to ambiguous natural images in spider phobia

Anke Haberkamp[a],[*],[1], Filipp Schmidt[b],[1], Melanie Biafora[c], Thomas Schmidt[c]

[a] *Philipps-University Marburg, Germany*
[b] *Justus-Liebig-University Giessen, Germany*
[c] *University of Kaiserslautern, Germany*

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ABSTRACT

Background and objectives: The fast detection of and response to threatening stimuli is an important task of the human visual and motor systems, and is especially challenging when stimuli are ambiguous. This study investigates the perception, evaluation and fast response to ambiguous natural spider stimuli in spider-fearful and non-anxious participants.

Methods: Stimuli were created by gradually morphing natural images of spiders and non-spiders (a crab, a starfish, a bunch of keys, and a flower). In Study 1, participants rated the images on perceptual and emotional dimensions and responded to them in a response priming task to measure rapid information processing. In Study 2, results were validated and extended in a different paradigm by using a go/no-go task.

Results: As expected, spider-fearful participants showed an interpretative bias for ambiguous stimuli (i.e., perceived them as more similar to spiders) and rated spider(-like) stimuli as more unpleasant, arousing, and disgusting. In Study 1, spider stimuli were preferentially processed in spider-fearful participants as observed in faster responses to spider targets–however, responses were not different to comparison participants for ambiguous stimuli. Study 2 suggests that this finding can be explained by differences in stimulus duration.

Limitations: No participants with positive attitudes towards spiders or a second fearful comparison group were included.

Conclusions: We suggest that these findings can be explained by the nature of the applied tasks that tap into early phases of visual processing, thereby relying on feedforward-mediated low-spatial-frequency information extracted via the fast, subcortical path to the amygdala.

1. Introduction

Imagine that someone who is extremely afraid of spiders enters a dark shed to collect the lawn mower: she looks to the ground and suddenly notices a small black object, causing her to startle. Only after this initial response does she realize that the object is a withered leaf instead of the dreaded spider. In general, the fast detection of and response to threatening stimuli in our environment is an important task of the human visual and motor systems. However, our visual perception is noisy; for example, because objects are occluded or hidden in shadows. This means that visual perception is often ambiguous and subject to interpretations dominated by top-down processes. These interpretations differ between individuals and depend on many factors. What are these factors and how do they affect visual and motor processing? Here, we are interested in evaluations of objects as fear-relevant or fear-irrelevant. Differences in these evaluations are most evident for individuals with anxiety disorders such as phobias.

Indeed, by definition, individuals with specific phobias suffer from a "marked fear or anxiety about a specific object or situation" (diagnostic criteria for specific phobia, DSM-5, American Psychiatric Association, 2013, pp. 197–198). In other words, they evaluate specific stimuli (e.g., spiders, snakes, dogs, or blood) or situations (e.g., heights, plane rides) or as strongly threatening, which are not necessarily regarded as such by non-anxious individuals. For example, a large number of studies have demonstrated that individuals with social phobia tend to interpret social situations as potentially threatening (e.g., Joormann & Gotlib, 2006; Kingsbury & Coplan, 2016; Miers, Blöte, Bögels, & Westenberg, 2008; Vassilopoulos & Banerjee, 2012; Voncken, Bögels, & Vries, 2003; for a review see; Heinrichs & Hofmann, 2001). Does this *interpretation bias* also play a role in specific phobias, which are associated with
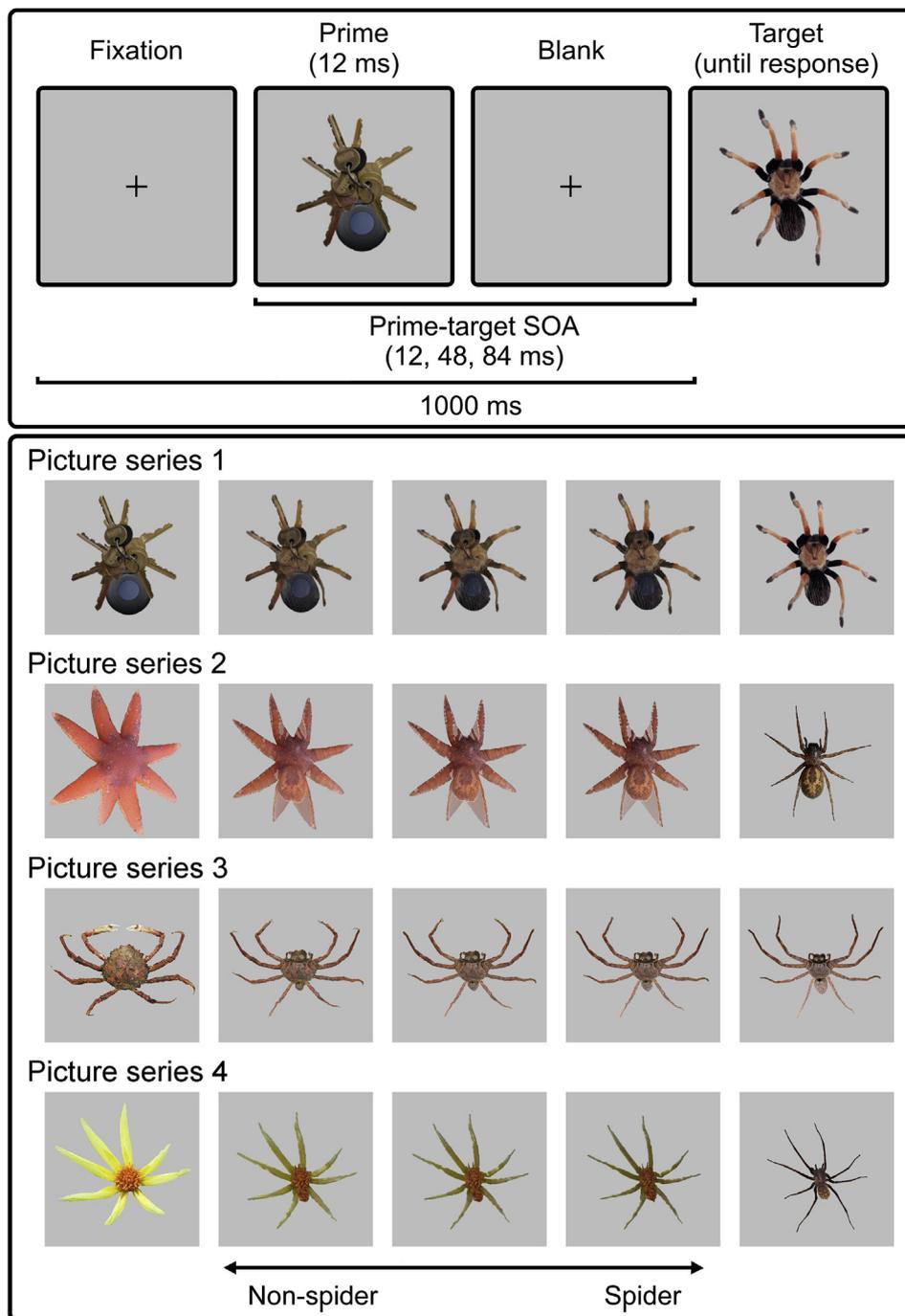
Fig. 1. Study 1. Procedure and stimuli. Upper panel: Primes and targets were presented in the sequence displayed. Lower panel: In each block, primes and targets were either drawn from morphed picture series 1, 2, 3, or 4. The prime was any of the five pictures; the target was either the first picture ("non-spider") or the last picture ("spider") in the respective series.

stimuli that are less ambiguous than social situations?

Becker and Rinck (2004) presented a series of scrambled pictures to spider-fearful and non-anxious participants. They interspersed this series with briefly (14 ms) presented pictures of spiders, beetles, and butterflies. They demonstrated that participants of the fearful group reported more frequently that they had seen a spider or a beetle. Thus, they seem to have a more liberal criterion when classifying perceptually similar animals as fear-relevant compared to the non-anxious group. Furthermore, Kolassa et al. (2006; 2007) presented schematic stimuli morphing between flower and spider images to spider-fearful and non-anxious participants (also see Visser, Haver, Zwitser, Scholte, & Kindt, 2016). Spider-fearful participants evaluated the images as more

unpleasant and arousing, and again, reported more frequently that ambiguous stimuli resembled a spider. Finally, spider-fearful participants tend to overestimate the size of a spider (Shiban et al., 2016; Vasey et al., 2012). This *visual interpretation bias* is one of many other biases prevalent among individuals suffering from spider phobia. Others are, for example, the *encounter expectancy bias* (i.e., the tendency to overestimate the likelihood of facing a spider: Mühlberger, Wiedemann, Herrmann, & Pauli, 2006); the *consequences expectancy bias* (i.e., overestimating the consequences of such a confrontation: Aue & Okon-Singer, 2015); the *memory bias* (i.e., a distorted recalling of past experiences with spiders: Mitte, 2008), and the extensively investigated *attentional bias* (i.e., attention is automatically drawn towards spiders

and then followed by avoidance behavior: Mogg & Bradley, 2006; Rinck & Becker, 2006; for a meta-analysis, see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007).

According to established cognitive theories (Beck & Clark, 1997; Clark & Wells, 1995; Eysenck, 1992, 2014; Mathews & MacLeod, 2005; Rapee & Heimberg, 1997; Williams, Watts, MacLeod, & Mathews, 1988), these biases play a major role in the development and maintenance of anxiety disorders. Thus, reducing such biases may lead to reduced anxiety and avoidance of feared stimuli and situations.

A number of studies tested this assumption by using bias modification techniques; however, meta analyses show small or no effects of *Cognitive Bias Modification* (Cristea, Kok, & Cuijpers, 2015; Hallion & Ruscio, 2011) or *Attentional Bias Modification* (Mogoaşe, David, & Koster, 2014). In addition, the few studies testing the potential role of interpretation bias in specific phobias report mixed results (Lester, Field, & Muris, 2011a, 2011b; Teachman & Addison, 2008). However, all of those studies used lexical stimuli (e.g., "You realize it is a spider") and focus on different interpretations of the fearful situation (e.g., "You think that it is harmless"). Further studies focusing on the therapeutic effects of bias modification techniques are desirable. Thus, therapeutic interventions may benefit from experimental results on biases in spider phobia.

In the line of research we are pursuing here, we use pictorial stimuli (e.g., images of spiders) and focus on different interpretations of the fearful stimulus itself (e.g., seeing a spider vs. a bunch of keys), an example of *visual interpretation bias* (e.g., Becker & Rinck, 2004; Haberkamp & Schmidt, 2015; Kolassa et al., 2007; Kolassa, Musial, Kolassa, & Miltner, 2006). Pictorial stimuli are more representative of the actual fearful situation or object compared to lexical stimuli, as they are thought to more directly access defensive motivational circuits (Lang, 1994; but see Van Den Hout, Jong, & Kindt, 2000), trigger stronger neural activations (Kensinger & Schacter, 2006), and are processed considerably faster (Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Schacht & Sommer, 2009). Taken together, these studies suggest that modifying the interpretation bias occurring on the level of visual information is potentially more powerful than modifying cognitive biases at later levels of processing. Therefore, reducing the visual interpretation bias using pictorial stimuli may be a promising tool to reduce anxiety in individuals with specific phobia. However, until today, few studies investigated the visual interpretation bias and little is known about information processing of ambiguous, fear-relevant stimuli. Do biased interpretations also affect visual information processing as has been suggested by previous studies (Becker & Rinck, 2004; Kolassa et al., 2006, 2007)?

In the present study, we focus on the role of visual interpretation bias for behavioral responses. Even though ambiguous stimuli are judged as more negative by individuals with specific phobia (Kolassa et al., 2006, 2007), dissociations between (slow) perception and (fast) motor responses have been reported frequently (Schmidt, Weber, & Haberkamp, 2016; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). Complementary to our previous study (Haberkamp & Schmidt, 2015), we collect responses to natural morphed images (Fig. 1, lower panel) from a group of spider-fearful participants and non-anxious comparison participants. These stimuli allow us to investigate effects of small stimulus changes on measures of perceptual interpretation and emotional significance, as well as on rapid information processing. We can measure these effects over different levels of stimulus ambiguity − equivalent to studies investigating processing of morphed emotional face stimuli in general populations (e.g. Duval, Moser, Huppert, & Simons, 2013; Haberman & Whitney, 2007; Schweinberger, Burton, & Kelly, 1999) and in clinical and subclinical samples with social phobia (e.g., Heuer, Lange, Isaac, Rinck, & Becker, 2010; Joormann & Gotlib, 2006). In order to present a variety of spider-like things that one might encounter in the natural environment, we chose four natural images for morphing (a crab, a starfish, a bunch of keys, and a flower) that varied in their visual appearance as

well as in their level of animacy (e.g., Nairne, VanArsdall, & Cogdill, 2017). This should increase generalizability of our findings beyond single stimuli.

In Study 1, we use a response priming task which measures rapid visuomotor information processing (e.g., Klotz & Neumann, 1999; Klotz & Wolff, 1995), and was previously applied to study visuomotor processing in fearful individuals (Haberkamp & Schmidt, 2014; Haberkamp, Schmidt, & Schmidt, 2013). In Study 2, we use a go/no-go task (e.g., Delorme, Richard, & Fabre-Thorpe, 2010; Fabre-Thorpe, 2011; Thorpe, Fize, & Marlot, 1996) to gather further information on the visuomotor processing of briefly presented morphed images. In the context of these paradigms, our research questions lead to three hypotheses. First, based on previous findings (e.g., Haberkamp et al., 2013; Öhman, Flykt, & Esteves, 2001) we expect enhanced processing (i.e., faster response times and stronger priming) of spider images in spider-fearful participants. Second, based on previous findings (e.g., Haberkamp & Schmidt, 2015; Kolassa et al., 2007), we expect a visual interpretation bias for ambiguous morph images, which would cause these images to be interpreted as spider-like in appearance. Third, we aim to test whether this visual interpretation bias also leads to enhanced processing of ambiguous natural images − in contrast to previous results with schematic stimuli (Haberkamp & Schmidt, 2015). To the best of our knowledge, the current studies are the first to investigate rapid processing of ambiguous natural stimuli in spider-fearful participants. If the visual interpretation bias for pictorial stimuli that was demonstrated in spider-fearful individuals transfers to behavioral responses, this would motivate studies testing modification of visual interpretation bias in specific phobia.

2. Study 1 (response priming)

One group of non-anxious and one group of spider-fearful participants responded to morphed natural images of spiders and non-spiders (Fig. 1). Spiders were assumed *fear-relevant* to non-anxious participants, but *phobic* to spider-fearful participants. Non-spiders were assumed *neutral* for the two groups. All stimuli were rated by the participants with respect to their perceptual similarity to a spider versus to a specific non-spider (*perceptual rating task*), as well as to the dimensions of valence, arousal, and disgust (*emotional rating task*).

We hypothesize that the perception of ambiguous morphed stimuli will be biased towards spiders in the group of spider-fearful participants (i.e., spider-fearful participants will more often classify ambiguous pictures as spiders). Those stimuli will be rated as being more unpleasant, arousing, and disgusting by spider-fearful participants (*emotional rating task*)–in contrast to the non-spider pictures and compared to the non-anxious comparison group. Also, we expect to observe priming for non-ambiguous stimuli of spiders and non-spiders in both groups (*priming task*). Based on previous studies, we assume that phobic stimuli will be preferentially processed by spider-fearful participants, resulting in faster responses to spider targets and stronger priming effects for spider primes (Haberkamp et al., 2013; Haberkamp & Schmidt, 2015). Advantages in information processing of phobic stimuli should occur compared to neutral stimuli (*within-group comparison*) as well as compared to the comparison group (*between-group comparison*).

Note that for ambiguous stimuli, categorical similarity between primes and targets is confounded with perceptual similarity. Consequently, priming effects can result from response as well as from perceptual priming (Haberkamp & Schmidt, 2015).

2.1. Methods

Both studies were approved by the Ethics Committee of the Faculty of Social Science of the University of Kaiserslautern.

2.1.1. Participants

Forty participants took part in two 1.5 h sessions. They received 7 €

per hour or course credit as payment. All had normal or corrected-to-normal vision and were naïve to the purpose of the study. They gave informed consent and were treated in accordance with the ethical guidelines of the American Psychological Association (APA). Before the start of the study, we invited individuals describing themselves as highly afraid of spiders or not afraid of spiders at all. These participants were recruited via university e-mail and bulletin boards and then screened with objective tests to confirm (or refute) their subjective appreciations (German version of the "Spider Phobia Questionnaire" SPQ; Hamm, 2006; original version by Klorman, Weerts, Hastings, Melamed, & Lang, 1974; German questionnaire "Fragebogen zur Angst vor Spinnen [Fear of spiders questionnaire]" FAS; Rinck et al., 2002). Refuted participants were remunerated for the time they needed to complete the questionnaires. For eligibility, non-anxious comparison participants had to score below the 25th percentile in the SPQ and spider-fearful participants above the 75th percentile. Participants also completed the Beck Depression Inventory II (BDI-II, German version by Hautzinger et al., 2006; original version by Beck, Steer, & Brown, 1996). Participants were excluded from the study when scoring > 18 in the BDI-II (indicating a clinically relevant depression). Based on these criteria two participants were excluded.

17 women and 3 men qualified for the spider-fearful experimental group (mean age 24.75 years, age range 19–40), and 14 women and 6 men (mean age 23.25 years, age range 18–30) for the non-anxious comparison group (Table 1). Participants also completed a structured diagnostic interview ("Diagnostic Interview for Psychological Symptoms (DIPS)" (Schneider & Margraf, 2011): 12 spider-fearful participants met all six criteria for a specific phobia, five participants met five and three participants met four. The criterion that was not satisfied in most cases (criterion E) states that the individual's fear, anxiety, or avoidance causes significant distress or significant interference in the person's day-to-day life. For this reason, we will refer to our participants as "fearful" instead of "phobic".

2.1.2. Apparatus

Participants were seated in front of a color cathode-ray monitor (1280 × 1024 pixels, retrace rate 85 Hz) at a viewing distance of approximately 60 cm.

2.1.3. Stimuli

Stimuli were naturally colored images of spiders and neutral non-spiders (a crab, a starfish, a bunch of keys, and a flower). Stimuli were designed by morphing spiders and neutral images to produce ambiguous stimuli. The non-spiders were chosen so that smooth transitions between spider and neutral images could be obtained (see Fig. 1). We used the GIMP Animation Package for GIMP 2.8.14 where morphs are based on interpolation between manually selected correspondence points (for the full morph sequences see supplementary videos S1-S4). This procedure generated 10 images for the morphs between crab/keys and spider and 12 images for the morphs between starfish/flower and spider.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.jbtep.2019.101495.

Table 1
Results of Mann-Whitney U tests with means and standard deviations (SDs) for spider-fearful and comparison participants in the spider questionnaire (German questionnaire "Fragebogen zur Angst vor Spinnen [Fear of spiders questionnaire]" FAS; Rinck et al., 2002), and the BDI-II (Beck Depression Inventory II, German version by Hautzinger, Keller, & Kühner, 2016).

	Spider fear	Comparison	Mann-Whitney-U	p
FAS	66.10 (16.43)	6.55 (7.67)	0.00	p < .001
BDI-II	6.75 (5.01)	6.20 (4.85)	197.00	ns

Note: *ns* = not significant.

2.1.4. Pilot study

In a pilot study, n = 40 participants (18 women) rated the images of each sequence (blocked, with single images presented in random order) according to how much they resembled a picture of the neutral image category (crab, starfish, keys, and flower) or a spider. For each sequence, we chose the two images that were rated as most resembling the neutral image category and the spider, and the image that was closest to a medium rating between both plus the two images adjacent in the ratings. Thus, we selected 5 images per morph sequence: the two least ambiguous (which always happened to be the original images) and the three most ambiguous images.

2.1.5. Response priming task

Response priming taps into the earliest phase of observable behavior (Klotz & Neumann, 1999; Klotz & Wolff, 1995; Schmidt, Haberkamp, & Schmidt, 2011; Vorberg et al., 2003). Participants classify visual target stimuli (e.g. spider images) as fast and as accurately as possible into different response categories (e.g. spider vs. non-spider). Targets were preceded by primes triggering either the same response as the targets (e.g. spider targets preceded by spider primes [consistent trials]) or the opposite response (e.g. non-spider targets preceded by spider primes [inconsistent trials]; cf. Fig. 1). In consistent trials, responses are usually faster and more accurate. In inconsistent trials, responses are slower and errors increase. The priming effect is defined by the difference in response times and error rates between consistent and inconsistent trials and increases with increasing time interval between prime and target (stimulus-onset asynchrony [SOA]) up to approximately 100 ms (Vorberg et al., 2003).

In the present experiment, all stimuli were presented against a light grey background (28.1 cd/m^2) in the middle of the screen. After the appearance of the central fixation point, the first stimulus (prime) was presented for 12 ms at fixation (7.63° visual angle). After a varying delay (SOAs of 12 ms, 47 ms, or 82 ms), the second stimulus (target) appeared at the same position and remained until participants classified the target as spider (non-spider) by pressing the right (left) response key (the assignment of response keys was counterbalanced across participants). The prime consisted of any image of a morph sequence; the target was always the non-ambiguous image of a spider or a (neutral) non-spider image from the same sequence (crab, starfish, keys or flower).

Each participant performed two separate sessions with 1200 trials each (40 blocks with 30 trials) plus a practice block. Participants received summary feedback on the speed and accuracy of their responses after each block. The diagnostic screening and the 1-h computer experiment were realized in the first session. The second session started with the 1-h computer experiment and was followed by an evaluation of the presented stimuli (emotional and perceptual rating task).

2.1.6. Stimulus validation (emotional rating task)

Stimuli were evaluated with a seven-point rating scale for three dimensions (*valence, arousal,* and *disgust*). Stimuli were presented one-by-one in random order and at the same position and size as in the priming task. For arousal and disgust, high scores reflect high levels and low scores low levels of experienced arousal or disgust, respectively. The scores of the valence rating were coded so that negative scores represent negative emotions and positive scores represent positive emotions toward the presented image (and zero neutral emotions).

2.1.7. Perceptual rating task

Additionally, participants rated the presented images according to their appearance, that is, their perceptual similarity to a spider or to a non-spider picture (crab, starfish, keys, or flower). Image presentation was the same as in the emotional rating task. Participants indicated their rating by pressing keyboard buttons corresponding to one of statements "The picture …" (1) "… very much looks like an non-spider", (2) "… somewhat looks like an non-spider", (3)"… slightly

looks like an non-spider", (4) "… neither looks like an non-spider nor like a spider", (5) "… slightly looks like a spider", (6) "… somewhat looks like a spider", and (7) "… very much looks like a spider". Participants were debriefed afterwards and received an explanation of the study.

2.1.8. Data treatment and statistical method

In the priming task, practice blocks were not analyzed; trials were eliminated if response times were shorter than 100 ms or longer than 1000 ms (0.83% of trials). The overall error rate was about 5.08% of all trials. Error trials were not included in the response time analyses. Repeated-measures analyses of variance (rmANOVAs) were performed separately for response times and error rates with Huynh-Feldt-corrected p values with the between-factor of group (G; comparison, spider fear), and within-factors of target (T; non-spider, spider), prime (P; morphed pictures 1 to 5), and SOA (S; 12, 48, 84 ms). Error rates were arcsine-transformed to comply with ANOVA requirements. We report F values with subscripts indicating the respective effect (e.g., F_{PxT} for the interaction of prime and target, i.e., the priming effect). Additionally, we report the effect size η^2 (cf. Levine & Hullett, 2002) in which 0.01 conventionally reflects a small, 0.059 reflects a medium, and 0.138 reflects a large effect (Cohen, 1988).

2.2. Results

2.2.1. Stimulus validation (emotional rating task)

Participants rated all stimuli (i.e., primes) on a seven-point rating scale for the dimensions *valence*, *arousal*, and *disgust*. These scores were separately submitted as dependent variables to univariate ANOVAs with factors of group (G; comparison, spider fear) and prime (P; morphed pictures 1 to 5). For all three scores, we obtained a main effect of group [all $F_G(1,790) > 278.03$, all $p < .001$, all $\eta^2 > 0.196$] and prime [all $F_P(4, 790) > 54.08$, all $p < .001$, all $\eta^2 > 0.140$], showing that spider-fearful participants rated spider pictures as more aversive on all three dimensions as compared to non-spider pictures and to ratings of comparison participants. This difference in ratings between spider-fearful and comparison participants increased monotonically with morphing [all $F_{GxP}(4, 790) > 14.08$, all $p = .001$, all $\eta^2 > 0.039$]. Comparison participants rated pictures as neutral and did not rate any of the pictures as particularly positive or negative, disgusting, or arousing (Fig. 2A). These results validate our procedure for choosing comparison participants and show that our stimuli are effective in inducing relevant emotions exclusively in spider-fearful participants.

2.2.2. Perceptual rating task

The perceptual score following from participants rating the stimuli (i.e., primes) according to their appearance was submitted as a dependent variable to a univariate ANOVA with factors of group (G; comparison, spider fear) and prime (P; morphed pictures 1 to 5). As expected, both groups assigned lowest ratings to non-spiders and increasingly higher ratings as the non-spider morphed into a spider [$F_P(4,790) = 394.52$, $p < .001$, $\eta^2 = 0.650$]. Importantly, the groups showed marked differences in their ratings: Spider-fearful participants had higher overall scores [$F_G(1,790) = 37.31$, $p < .001$, $\eta^2 = 0.015$], specifically for the three most ambiguous pictures [$F_{GxP}(4,790) = 5.68$, $p < .001$, $\eta^2 = 0.009$]. This shows that compared to comparison participants they generally perceived morphed pictures to bear more resemblance to a spider than to the respective non-spider (Fig. 2D).

We calculated Pearson product-moment correlations based on the individual ratings per participant and per picture. In both groups, we obtained significant correlations for all ratings, which were stronger in spider-fearful participants (Table 2). In this group, pictures that were perceived as more spider-like evoked more negative emotions.

2.2.3. Response priming task

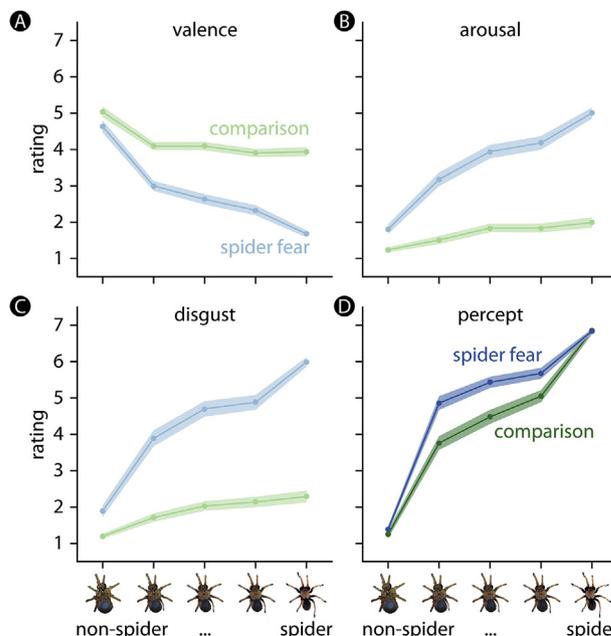We performed a fully-factorial rmANOVA to analyze our results

Fig. 2. A-C) Emotional rating scores (valence, arousal, and disgust) for the prime pictures separately for each group and across categories. Higher scores reflect more positive emotions (valence), higher arousal and higher disgust, respectively. D) Perceptual appearance scores for the prime pictures separately for each group and across categories. Higher scores reflect higher similarity of the stimulus to a spider. In all panels, error bars denote standard errors of the mean.

Table 2
Correlation coefficients and *p*-values for the Pearson product-moment correlations between the different emotional ratings and the perceptual ratings across all pictures separately for both groups.

	Spider Fear		Comparison	
	Pearson's r	*p*	Pearson's r	*p*
Emotional rating				
Valence	-.589	*p <* .001	-.308	*p <* .001
Arousal	.584	*p <* .001	.250	*p <* .001
Disgust	.610	*p <* .001	.314	*p <* .001

with respect to priming effects and target effects for spider-fearful and comparison participants.

2.2.3.1. Influence of the primes on priming effects. Priming effects are defined as the difference between the responses to the non-spider and spider targets as a function of the morphed primes. Priming effects depended strongly on the morphed primes, in response times [$F_{TxP}(4,152) = 272.37$, $p < .001$, $\eta^2 = 0.244$] as well as in error rates [$F_{TxP}(4,152) = 106.19$, $p < .001$, $\eta^2 = 0.381$] (Fig. 3). Responses to the non-spider targets were fastest and most accurate when presented after the non-spider prime but increasingly slower and less accurate when the prime morphed into a spider. Equivalently, responses to the spider targets were fastest and most accurate when presented after the spider prime but increasingly slower and less accurate when the prime morphed into a non-spider picture. Moreover, priming effects increased with SOA in response times [$F_{TxPxS}(8,304) = 21.25$, $p < .001$, $\eta^2 = 0.048$] as well as in error rates [$F_{TxPxS}(8,304) = 16.55$, $p < .001$, $\eta^2 = 0.109$] (cf. Schmidt et al., 2011; Vorberg et al., 2003).

Importantly, overall priming effects in response times and error rates were not different between spider-fearful and comparison participants [$F_{GxTxP}(5,152) = 0.40$, $p = .811$, $\eta^2 = 0.001$;
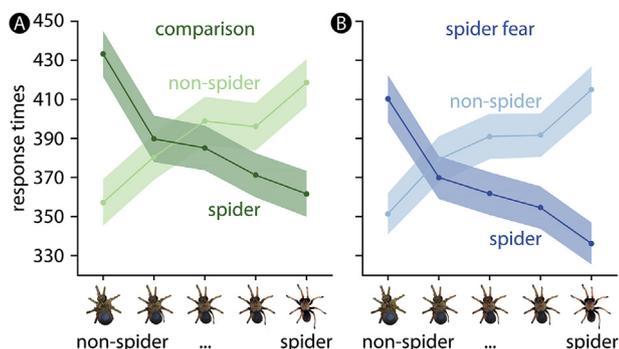
Fig. 3. Response times [ms] to spider and non-spider targets as a function of prime picture separately for A) comparison group and B) spider-fearful participants, and averaged across SOA. Error bars denote standard errors of the mean with pure intersubject variance removed (Cousineau, 2005).
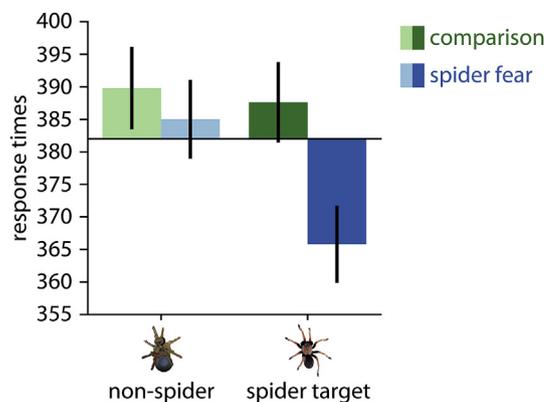

Fig. 4. Response times [ms] to spider and non-spider targets, separately for each group and averaged across SOA. Response times are shown relative to the grand average response time of 382 ms. Error bars denote standard errors of the mean.

$F_{GxTxP}(4,152) = 2.53$, p = .063, $\eta^2 = 0.015$], showing that the differences between groups in the perceptual and emotional ratings of *ambiguous stimuli* did not translate to differences in priming effects (Haberkamp & Schmidt, 2015). This was also the case when analyzing results for animate (starfish, crab) and inanimate (keys, flower) stimuli separately. But what about potential effects of non-ambiguous stimuli? To test whether our results are in line with previous reports of enhanced information processing for non-ambiguous natural stimuli (e.g., Haberkamp et al., 2013; Haberkamp & Schmidt, 2015), we calculated rmANOVAs including only the most discernible primes (i.e., the non-spider and spider pictures). To allow for a meaningful analysis, we defined a new within-factor of consistency (C; consistent, inconsistent), coding whether the target was in the same category (non-spider, spider) as the prime–so that a significant effect of consistency corresponds to a significant priming effect. Indeed, we observed a three-way interaction of group, prime, and consistency in response times $[F_{GxPxC}(1,38) = 8.09$, p = .007, $\eta^2 = 0.014$] but not in error rates: specifically, response time priming was stronger for spider primes compared to non-spiders in spider-fearful participants (78.64 ms vs. 58.81 ms), and vice versa in comparison participants (56.83 ms vs. 75.98 ms). Finally, we did find a significant main effect of the primes on response times and error rates $[F_P(4,152) = 7.53$, p < .001, $\eta^2 = 0.008$; $F_P(4,152) = 5.30$, p = .001, $\eta^2 = 0.020$, respectively] as well as interactions of prime and SOA on response times $[F_{PxS}(8,304) = 2.40$, p = .016, $\eta^2 = 0.005$]; however, these effects were numerically small and did not vary smoothly with the degree of morphing. We also found interactions of target and SOA $[F_{TxS}(2,76) = 12.00$, p < .001, $\eta^2 = 0.011$; $F_{TxS}(2,76) = 13.49$, p < .001, $\eta^2 = 0.035$]: responses were increasingly faster and relatively more accurate with longer SOAs for spider targets, and increasingly slower and relatively less accurate with longer SOAs for non-spider targets.

2.2.3.2. Influence of the targets on overall response times. Responses were faster to spider than to non-spider targets $[F_T(1,38) = 12.86$, p = .001, $\eta^2 = 0.017$; not significant in the error rates]. Crucially, we observed differences for response times to spider and non-spider targets between the groups $[F_{GxT}(1,38) = 8.40$, p = .006, $\eta^2 = 0.011$] (Fig. 4). Spider-fearful participants responded faster to spider targets [M = 365.81 ms, SD = 101.71] than to non-spider targets [M = 385.02 ms, SD = 103.70]. This was not the case for comparison participants (spider targets [M = 387.62 ms, SD = 106.40], non-spider targets [M = 389.81 ms, SD = 108.89]).

2.3. Discussion

To investigate rapid information processing of ambiguous stimuli in spider-fearful individuals, we morphed natural images of spiders into

neutral images of a crab, a starfish, a bunch of keys, and a flower. The most ambiguous and the most non-ambiguous stimuli were identified in a pilot study. Results of the perceptual and emotional rating tasks showed that spider-fearful individuals rated ambiguous stimuli as appearing more spider-like. They evaluated stimuli as being more unpleasant, arousing, and disgusting compared to the non-spider stimuli (within-group comparison) but also compared to the ratings of the comparison group (between-group comparison). The results of both rating tasks validate the morphed stimuli by demonstrating a perceptual as well as an emotional bias in spider-fearful participants.

We expected the ambiguous stimuli to be differently processed in the two groups – with enhanced information processing in spider-fearful individuals (*Response Priming Task*) for spiders and spider-like images. In general, we found robust priming effects in the two groups: responses to non-spider targets were faster and more accurate when targets were preceded by non-spider or non-spider-like primes and increasingly slower and less accurate when the primes gradually morphed into a spider (and vice versa for spider targets). When considering non-ambiguous primes, we found the expected pattern of results in priming effects: In spider-fearful individuals, priming effects were larger for spider primes compared to neutral primes (*within-group comparison*) and to comparison participants (*between-group comparison*).

However, a closer look at the results show that the larger priming effects might be driven by a target effect alone. This is illustrated in Fig. 3, which shows that spider-fearful participants respond generally faster to spider targets, no matter whether the prime is consistent or inconsistent (downward shift of responses to the spider targets: dark green vs. dark blue lines). This pattern of results is surprising: if we assume that phobic stimuli are processed more efficiently, should not the same apply to the primes?

One possibility is that there is a processing enhancement only for phobic targets but not for phobic primes: maybe the primes are presented too shortly (presentation time 12 ms) so that their impact cannot be modulated by spider fear (average presentation time of targets ~380 ms). Indeed, there is evidence from semantic priming showing that interpretation of ambiguous primes by high trait anxious individuals varies as a function of time (Richards & French, 1992). In addition, the prime is followed by a target image at the same screen position, which might further curtail the processing of the prime (e.g., by pattern masking which can interfere with priming; Schmidt et al., 2011). A second possibility is that the spider-fearful participants developed a bias towards the response key associated with the spider. If the spider response required a lower motor threshold or was always pre-activated in fearful participants, we would expect responses to be systematically faster for consistent as well as inconsistent trials, without necessarily altering the priming effect–which is exactly the data pattern
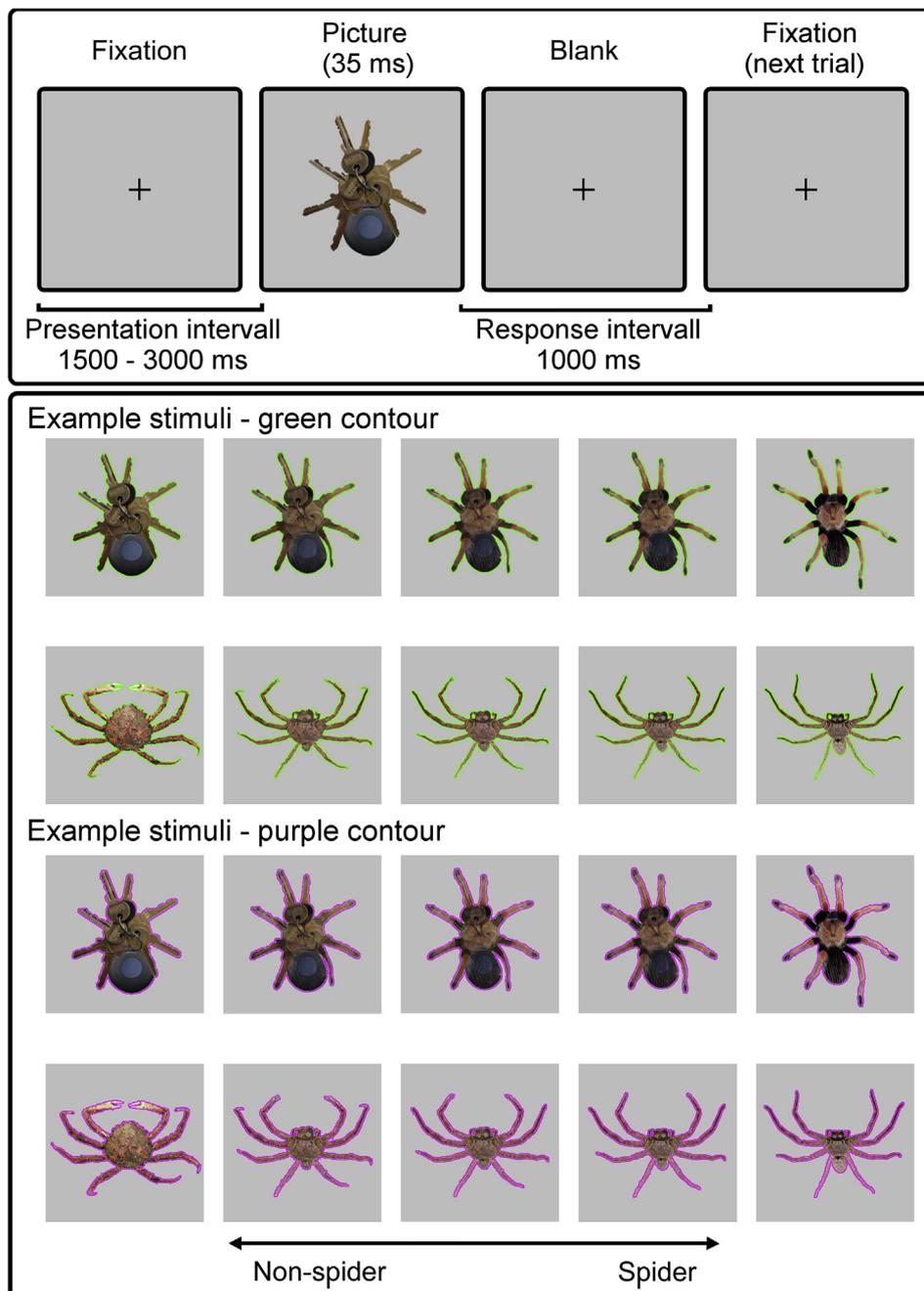
Fig. 5. Study 2. Procedure and stimuli. Upper panel: Stimuli were presented for 35 ms after a random interval between 1500 and 3000 ms. Go responses or no-go responses were registered within a time interval of 1000 ms after stimulus presentation. Lower panel: In the *Color Task*, stimuli were drawn from one of the four morphed picture series and randomly presented with a green or purple contour. In the *Spider/Non-spider Task*, non-ambiguous stimuli of spiders or non-spider (crab, keys, starfish, or flower) were presented. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

observed in Study 1.

Study 2 was designed to allow for longer presentation of the prime without the need for a subsequent target and to eliminate the possibility of a bias towards one particular response key. Specifically, we employed go/no-go tasks that require only one response key and only a single stimulus (e.g., Delorme et al., 2010). We used the morphed primes from Study 1 in two tasks. In the *Color Task*, we collected go/no-go responses to all of our morph stimuli. Because morphs cannot be unambiguously classified as spiders or non-spiders, we cannot use a straightforward classification scheme (such as spider vs. non-spider). Therefore, we added a green or purple contour to the stimuli and asked participants about these colors (Fig. 5). As the color information is at the same spatial location as the shape (contour) information and in

close spatial proximity to the texture information, we assumed that this would maximize the probability of visual processing of the ambiguous stimuli. Also, in contrast to the distinct visual processing of colors and words (e.g., Emotional Stroop Task; Watts, McKenna, Sharrock, & Trezise, 1986), the processing of color is an intrinsic part of object recognition so that our stimuli should be processed together with their colored frames along the same visual pathways. Participants had to release the response key on *go trials* (e.g. when a stimulus with a green contour was presented) and keep holding it down on *no-go trials* (e.g. when a stimulus with a purple contour was presented).

As we could not completely rule out that participants would be able to suppress any visual processing of other stimulus information than the task-relevant colors, we applied a second task where they had to

process the relevant stimulus information to complete the task. In the *Spider/Non-spider Task*, we collected go/no-go responses to non-ambiguous stimuli only. Participants responded either to spiders or non-spiders and released the response key on *go trials* as fast as possible (e.g., when an image from the relevant category was presented) and keep holding it down on *no-go trials* (e.g., when an image of the other category was presented).

We assumed that spider stimuli would be preferentially processed by spider-fearful individuals (as ambiguous stimulus and color contours are at the same spatial location, attentional capture by fear-relevant stimuli (Gerdes, Alpers, & Pauli, 2008) cannot distract them away from the (color) task). The enhancement should be evident in faster responses to spider and spider like-stimuli compared to non-spider and non-spider-like stimuli (*within-group comparison*) as well as compared to responses to spider and spider-like stimuli in the non-anxious comparison group (*between group comparison*).

3. Study 2 (go/no-go tasks)

3.1. Methods

3.1.1. Participants

Forty participants were recruited as described in study 1. They took part in one session, taking 1.5–2 h. 20 participants (14 women, age range 19–28, mean age 23.50 years) qualified for the spider-fearful and 20 participants (14 women, age range 20–37, mean age 24.84 years) for the non-anxious comparison group (Table 3). Seven participants were excluded after the diagnostic session due to our exclusion criteria (three due to high scores in the BDI-II, four participants scored too high or too low in the SPQ to qualify for either of the two groups).

3.1.2. Apparatus

See Study 1.

3.1.3. Stimuli and procedure

We used two go/no-go categorization tasks similar to that of Delorme et al. (2010). Images were presented at fixation against a lighter grey background (28.1 cd/m^2). They appeared for 35 ms at random intervals ranging from 1.5 to 3 s after a central fixation point. Participants pressed the space bar with their dominant index finger and kept holding it down while identifying the image. In the *Color Task*, participants either had to release the key as fast as possible when a purple-framed stimulus was presented (*go trial*) and to keep holding it down when a green-framed stimulus was presented (*no-go trial*). The mapping of colors to responses was counterbalanced across participants. After a delay of 1 s after stimulus presentation, responses were either counted as go responses (if the key was released), or as no-go responses (if the key was not released). Feedback tones after each trial indicated correct (high-pitched tone) or incorrect responses (low-pitched tone). Participants completed one practice block followed by 9 blocks of 40 trials.

In the *Spider/Non-spider Task*, each participant responded to non-ambiguous stimuli (Fig. 1, lower panel: stimuli on the left and right) in two different sessions. In one session, they had to release the key as fast as possible when a spider was presented (*go trial*) and to keep holding it

down when a non-spider was presented (*no-go trial*), and vice versa in the other session. The order of sessions was random for each participant. In each session, participants completed one practice block followed by 4 blocks of 40 trials. Note that at the time of the *Spider/Non-spider Task*, only 20 participants were able to participate (10 in each group).

3.1.4. Stimulus validation (emotional rating task)

Stimuli were rated as described in Study 1. We adjusted the presentation time to 35 ms as in the go/no-go categorization tasks.

3.1.4. Perceptual rating task

This task was administered as in Study 1. Stimuli were presented for 35 ms.

3.1.6. Data treatment and statistical methods

Practice blocks were not analyzed. Responses with response times > 1000 ms were classified as no-go responses. Hits were defined as go responses on go trials, false alarms as go responses on no-go trials. In the *Color Task*, all data of one comparison participants was lost due to instruction failure, while another participant did only complete 52% of trials due to a technical error; in the remaining responses errors occurred in 2.9% of trials (0.9% misses and 2.0% false alarms) with 48.4% hits and 48.6% correct rejections. In the *Spider/Non-spider task*, error rate was 8.9% (3.6% misses and 5.3% false alarms) with 46.3% hits and 44.7% correct rejections when targets were spiders and 10.1% (4.1% misses and 6.0% false alarms) with 45.9% hits and 44.0% correct rejections when targets were non-spiders. For analysis, we subjected response times from hit trials to rmANOVAs with Huynh-Feldt-corrected *p* values with the between-factor of group (*G*; comparison, spider fear) and the within-factor of target (*T;* morphed pictures 1 to 5).

3.2. Results

3.2.1. Stimulus validation (emotional rating task)

We analyzed the results for the emotional ratings (*valence, arousal, disgust*) in comparison and spider-fearful participants (Fig. 6A–C) by
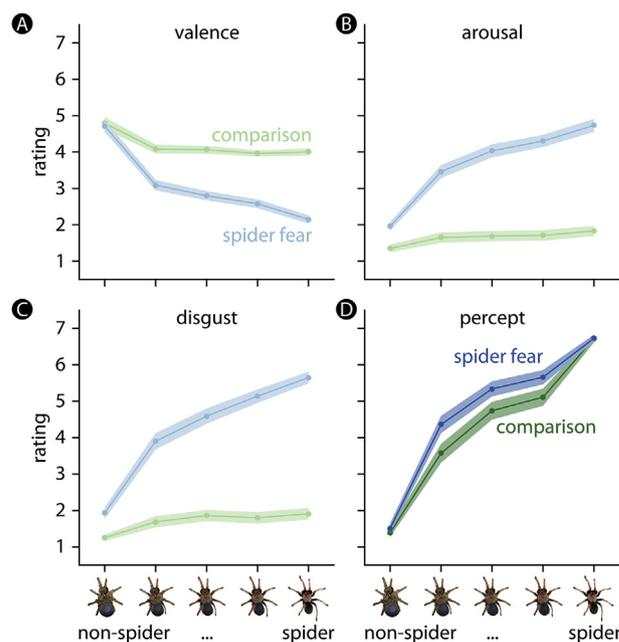
Fig. 6. A-C) Emotional rating scores (valence, arousal, and disgust) for the prime pictures separately for group and across non-spider categories. D) Perceptual appearance scores for the prime pictures separately for group and across categories (cf. Fig. 2).

Table 3
Results of Mann-Whitney U tests with means and standard deviations (SDs) for spider-fearful and comparison participants in the BDI-II, and the spider questionnaire FAS.

	Spider fear	Comparison	Mann-Whitney-U	*p*
FAS	58.90 (20.71)	5.16 (9.25)	4.00	*p* < .001
BDI-II	6.40 (4.07)	5.63 (4.74)	170.00	*ns*

Note: *ns* = not significant.

submitting them to three univariate ANOVAs with factors of group (G; comparison, spider fear) and target (T; morphed pictures 1 to 5). The results closely replicated those of the emotional rating task in Study 1. We obtained main effects of group [all $F_G(1,790) > 205.44$, all $p < .001$, $\eta^2 = 0.160$] and target [all $F_T(4, 790) > 34.86$, all $p < .001$, $\eta^2 = 0.094$] as well as an interaction effect [all $F_{GxT}(4, 790) > 14.39$, all $p < .001$, $\eta^2 = 0.044$] for all three scores. Spider-fearful participants rated spider pictures as aversive on all three dimensions. This effect increased with morphing.

3.3. Perceptual rating task

Perceptual scores were submitted to a univariate ANOVA with factors of group (G; comparison, spider fear) and target (T; morphed pictures 1 to 5). As in Study 1, the lowest ratings of both groups were assigned to the non-spider pictures and ratings monotonically increased with the non-spider morphing into a spider [$F_T(4,790) = 858.61$, $p < .001$, $\eta^2 = 0.513$]. Spider-fearful participants had higher overall scores [$F_G(1,790) = 46.92$, $p < .001$, $\eta^2 = 0.007$], specifically for the three ambiguous pictures [$F_{GxT}(4,790) = 6.11$, $p < .001$, $\eta^2 = 0.004$] (Fig. 6D). Again, we obtained strong correlations between emotional and perceptual ratings (Table 4) with substantially higher coefficients in the spider-fearful group.

3.3.1. Color task

We did not find any difference between comparison and spider-fearful participants in terms of response times (for details see Table A1 in the Appendix): even though correct responses (i.e., hits) were faster as stimuli became more spider-like [$F_T(4,144) = 30.53$, $p < .001$, $\eta^2 = 0.046$], we found no difference between groups [$F_{GxT}(4,144) = 1.45$, $p = .224$, $\eta^2 = 0.002$] (Fig. 7A).

Because go/no-go tasks are well suited to analyze the time course of processing, we also calculated d' curves (*signal detection theory*; Macmillan & Creelman, 2009) with d' values at a given time based on the cumulative hits and false alarms of all responses up to that time (Fig. 8). However, we did not see any differences between groups (i.e., very similar time course of performance and overlap of 95% confidence intervals).

3.3.2. Spider/Non-spider task

We could not preclude that the attentional selection of task-relevant color information might have overrun potential group effects in the *Color Task*. In other words, spider-fearful participants might have failed to show enhanced visual processing of spider targets because they attended only the color but not the shape of the non-spiders. Thus, we applied a second *Spider/Non-spider Task* (Fig. 7B).

As in the *Color Task*, we did not find any differences between comparison and spider-fearful participants (for all results see Table A2 in the Appendix). Again, correct responses (i.e., hits) towards spiders were generally faster compared to responses to non-spiders [$F_T(1,18) = 7.97$, $p = .011$, $\eta^2 = 0.042$] but not different between groups [$F_{GxT}(1,18) = 0.00$, $p = .961$, $\eta^2 = 0.000$] (Fig. 7B). Furthermore, d' curves show identical early time courses of processing for

Table 4
Correlation coefficients and *p*-values for the Pearson product-moment correlations between the different emotional ratings and the perceptual ratings across all pictures separately for both groups.

	Spider Fear		Comparison	
	Pearson's r	p	Pearson's r	p
Emotional rating				
Valence	-.534	p < .001	-.186	p < .001
Arousal	.572	p < .001	.181	p < .001
Disgust	.614	p < .001	.189	p < .001
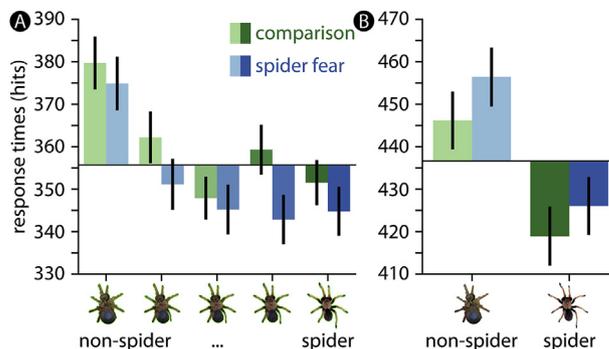
Fig. 7. Response times [ms] in correct trials (i.e., hits) as a function of target picture type, shown separately for each group in the A) *Color Task*, and B) *Spider/Non-spider Task*. Error bars denote standard errors of the mean with pure intersubject variance removed (Cousineau, 2005). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
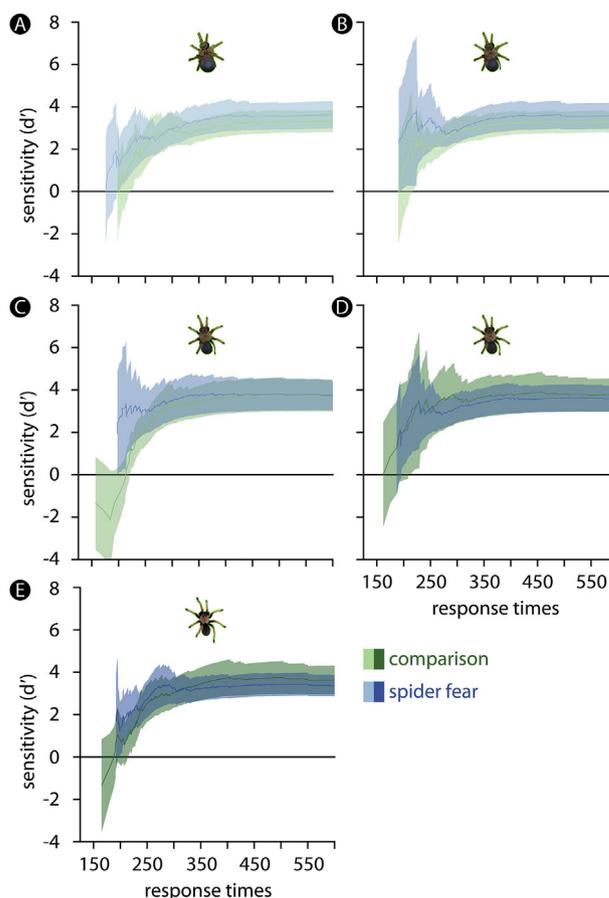
Fig. 8. The time course of processing in the *Color Task*, separately for each target picture type from A) non-spider to E) spider. d' curves are plotted as a function of response time with d' values at a given time based on the cumulative hits and false alarms of all responses up to that time. Error bars denote 95% confidence intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

comparison and spider-fearful participants for non-spiders and spiders (Fig. 9) and also within the group of spider-fearful participants (comparison between the light and dark blue line). Only in later processing (i.e., in slower responses), spider-fearful individuals show a somewhat lower performance compared to comparison participants, however equally so for non-spiders and spiders.
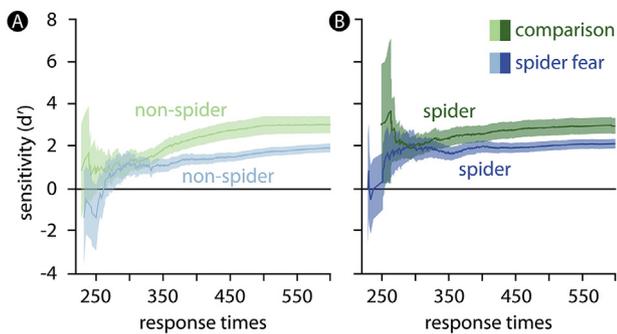
Fig. 9. The time course of processing in the *Spider/Non-spider Task*, separately for A) non-spider and B) spider targets. For details see Fig. 8.

3.4. Discussion

Study 2 replicates our findings in the *perceptual* and *emotional rating tasks*: spider-fearful individuals rated ambiguous stimuli as being more spider-like and more unpleasant, arousing, and disgusting. We expected that spider and spider-like stimuli would be preferentially processed by spider-fearful individuals, resulting in faster responses to the phobic stimuli in the go/no-go tasks. However, although the stimuli were clearly classified and evaluated differently, we did not find preferential processing of phobic stimuli in spider-fearful individuals, neither in the *Spider/Non-spider* nor in the *Color Task*. In both tasks, comparison and spider-fearful participants responded faster to spiders compared to non-spiders, but responses were not different between groups. Thus, our hypothesis was not supported, even though stimuli were presented for a longer time and with no second stimulus that might interfere with their processing.

4. General discussion

In the current study, we investigated rapid information processing of ambiguous stimuli. Spider-fearful participants responded faster when phobic stimuli appeared as *targets*, and priming effects appeared larger for spider *primes*. We suggest that in everyday behavior this would relate to automatic, reflexive responses, for example, the first twitching or recoiling immediately after seeing a spider (or after interpreting a dirt spot as a spider; cf. Rinck, Kwakkenbos, Dotsch, Wigboldus, & Becker, 2010). However, the difference in priming effects is likely driven by the faster responses of spider-fearful participants to spider targets that occurred irrespective of prime consistency. Thus, target effects alone can explain the stronger priming effects by phobic primes. This is surprising because more efficient processing of phobic stimuli should not only lead to faster responses to phobic targets, but also to stronger priming from phobic primes (Schmidt et al., 2011). Why is it so difficult to observe a genuine modulation of priming effects by phobic primes?

We suspected that these different effects of identical phobic stimuli when used as targets versus primes follows from the short presentation time of the prime – and from the subsequent target presentation at the prime location, which may interfere with processing of the prime. Therefore, we used a go/no-go tasks that allowed for longer presentation times and involving only a single stimulus. In two go/no-go tasks, we showed that spider-fearful individuals and comparison participants responded similarly to the different image classes: Both groups responded faster to spiders than to non-spiders, but there was no difference between the groups. Why are responses not faster towards briefly presented phobic stimuli even though previous go/no-go studies demonstrated enhanced processing of relevant visual stimuli (e.g., of personally familiar faces compared to unfamiliar faces; Caharel, Ramon, & Rossion, 2014; Ramon, Caharel, & Rossion, 2011)?

An explanation in terms of a response bias towards the spider-related response key is ruled out by Study 2: spider-fearful individuals

may have a lower motor threshold to initiate the keypress responses, use more force and thus higher velocity to move the key, or tonically pre-activate the spider-related response (Study 1). Yet, in Study 2 there was only one response key and we still did not observe differences between groups. An alternative explanation is that spider-fearful participants aim to avoid spiders as fast as possible. This would explain faster responses to spider targets in Study 1 because spider targets disappeared after participants' responses. In Study 2, however, spider images were briefly presented and stimulus duration was uncorrelated with participants' responses (i.e. spider-fearful participants did not benefit from accelerated responses). This might have reduced the participants' motivation for speeded responses in comparison to Study 1. Still, studies on spider phobia with constant stimulus durations (i.e. where participants' responses did not trigger disappearance of the spider pictures) did also report faster responses in the groups of spider-fearful individuals (e.g. Peira, Golkar, Larsson, & Wiens, 2010; Soares & Esteves, 2013). Thus, it is unlikely that our results are simply following from avoidance behavior of the group of spider-fearful individuals. So, what other phenomenon might explain the current findings? We suggest that the presentation time of stimuli was to brief to modulate emotional processes.

There is a long-standing debate about the neural bases of emotional signals, especially about the neural pathways along which these signals are travelling through the brain. Some authors argue that the initial analysis of emotional signals proceeds along a specialized subcortical pathway through the superior colliculus and pulvinar to the amygdala, bypassing primary visual cortex and supporting rapid processing of emotional stimuli (LeDoux, 1998; Ohman, 2005; Skuse, 2006; Tamietto & Gelder, 2010). Others propose that the processing merely involves direct cortico-cortical connections (i.e., the ordinary object recognition system) and that there is no clear anatomical evidence for the subcortical route of processing (Pessoa & Adolphs, 2010; Valdés-Sosa et al., 2011).

Recently, two studies provided direct evidence for the existence of a subcortical pathway on a neuronal level but also pointed out incidental limitations in processing (Inagaki & Fujita, 2011; Méndez-Bértolo et al., 2016). In an electrophysiological study in human patients, Méndez-Bértolo et al. (2016) measured intracranial event-related potentials and showed that the amygdala discriminated fearful faces from neutral or happy ones as early as 74 ms after stimulus onset – faster than responses in visual cortex. Importantly, these fast amygdala responses were limited to the low-frequency information in the fearful faces, in line with earlier accounts of magnocellular input to the amygdala (e.g., Carretié, Hinojosa, López-Martín, & Tapia, 2007; Inagaki & Fujita, 2011; Johnson, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003). Single cell recordings in monkeys corroborated this finding. Inagaki and Fujita (2011) demonstrated that responses of amygdala neurons to emotional faces, especially threatening ones, occurred as early as 50 ms after stimulus onset – again faster than responses in visual cortex.

Those properties of a fast, subcortical processing route for emotional signals can explain our results. The response priming as well as the go/no-go paradigm are both tapping into the earliest phases of visuomotor processing. Lamme and Roelfsema (2000) propose that this earliest wave of feedforward processing can be distinguished from a later phase of widespread intracortical feedback. While this later phase allows for more elaborate processing of the stimuli, the feedforward phase is based on low-level stimulus information resulting in low spatial frequency representations of stimuli (Hegdé, 2008). The response priming as well as the go/no-go paradigm ask for speeded responses at the limit of what participants can accomplish and are likely to be based on feedforward signal processing (e.g., Fabre-Thorpe, 2011; Thorpe et al., 1996). Because the overall shapes of our spider and non-spider stimuli were similar – to allow for smooth image morphing – they might have been undistinguishable in low spatial frequencey representations (Fig. 10). Thus, the coarse low-frequency representation of the phobic primes (or go/no-go stimuli) when processed via the fast, subcortical
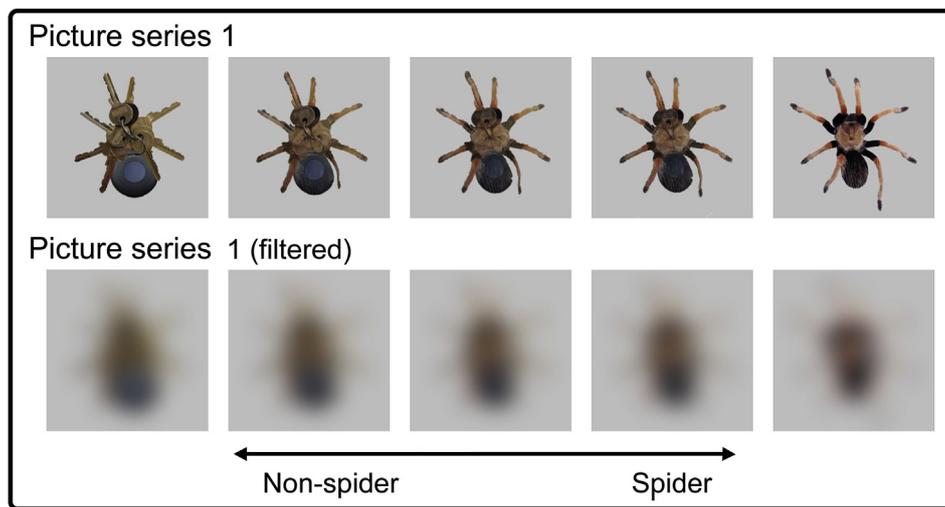
Fig. 10. Example stimuli with a Gaussian low-pass filter that removes all spatial frequencies > 0.5 cycles/degree (cf. Legge, 1978).

path to the amygdala (Inagaki & Fujita, 2011; Méndez-Bértolo et al., 2016) was presumably not detailed enough to identify tell-tale shape features.

This is in line with the findings of Becker and Rinck (2004): they briefly presented pictures of spiders, beetles, and butterflies (14 ms) embedded into a series of scrambled pictures, and showed that spider fearful participants reported more frequently that they had seen a spider or a beetle (i.e., two perceptually similar animals) but not a butterfly. The authors demonstrated that this followed from an interpretation bias but not from an improved detection of (or sensitivity to) threat, illustrating difficulties of telling apart shortly presented stimuli. In a visual search task with images of threat-relevant (spiders, snakes) and neutral animals (frogs, cockroaches) with healthy participants, Gao, LoBue, Irving, and Harvey (2017) report a processing advantage of threatening stimuli, even when those were low-pass filtered. However, they also find that the majority of the variance was accounted for by visual similarity of their stimuli. As our stimuli were visually similar − again, to allow for smooth image morphing − this would explain why phobic stimuli affect motor responses when presented for an extended period of time (target effects) but not when presented only briefly (priming effects, go/no-go responses).

If this is true, how can we explain the results of the emotional and perceptual rating task with briefly presented stimuli (Study 2)? Here, ambiguous stimuli are clearly rated differently by spider-fearful participants compared to comparison participants. We suggest that this follows from the different affordances of rating and motor tasks. In the rating tasks, participants were not asked to perform speeded responses. Thus, even though stimuli were presented just for the blink of an eye, participants took their time to make their judgments. This additional time allows for top-down processes, including working memory operations and other feedback-mediated processing (Desimone & Duncan, 1995; Lamme & Roelfsema, 2000; Treisman & Gelade, 1980). Previous work showed how information rapidly accumulates over time when stimuli are not masked (Bacon-Macé, Macé, Fabre-Thorpe, & Thorpe, 2005). In cueing tasks, designed to shape the distribution of spatial attention across the visual field, threatening cues affected target responses at 100-ms cue presentation time but not at 28-ms presentation time in highly anxious individuals (Koster, Crombez, Verschuere, Vanvolsem, & Houwer, 2007).

Indeed, most experimental studies in the literature presented the critical stimuli for extended periods of time or without any time restrictions. Examples include *visual search* (e.g., Öhman et al., 2001), *emotional stroop* (Williams, Mathews, & MacLeod, 1996), *dot probe* (MacLeod, Mathews, & Tata, 1986) and *emotional cueing* (Fox, Russo, Bowles, & Dutton, 2001; Van Bockstaele et al., 2014). In contrast,

responses in our response priming and go/no-go tasks were given as quickly as possible, thereby tapping into earlier stimulus representations, favoring feedforward-mediated bottom-up rather than accumulated top-down information.

In the introduction, we speculated that the visual interpretation bias might be a new promising venue for bias modification techniques. A possible technique would be to pair positive feedback with responses identifying ambiguous pictorial stimuli as non-threatening. The resulting modification of the visual interpretation bias would potentially tap into relatively early level of visual information processing compared to later levels of cognition. However, we did not find any differences in early visual information processing (as measured by response priming and go/no-go tasks), at least for brief stimulus presentations. This suggests that a modification of the visual interpretation bias would not be more effective compared to techniques based on lexical stimuli and cognitive interpretations (Lester et al., 2011a, 2011b; Teachman & Addison, 2008).

5.1. Limitations and future studies

First, we did not include participants with positive attitudes towards spiders (spider aficionados) or a second fearful comparison group (e.g., individuals with social phobia) to rule out the possibility that spider stimuli would be effective because of their emotional salience rather because of fear, or to rule out the possibility that spider stimuli would be effective also in other individuals with anxiety disorders. However, note that there is previuos evidence suggesting that attentional biases as well as enhanced information processing in spider phobia is indeed limited to (phobic) spider stimuli (e.g., Haberkamp et al., 2013; Soares, Esteves, Lundqvist, & Ohman, 2009; Öhman et al., 2001).

Second, we might have fostered response biases in participants by specifically recruiting participants with a self-reported fear of spiders or no fear of spiders. However, note that our diagnostic procedure is the same as that of previous studies with spider-fearful individuals (e.g., Becker & Rinck, 2004; Haberkamp et al., 2013; Lipp & Waters, 2007).

Third, future studies should validate our conclusions by testing phobic stimuli in go/no-go tasks with different stimulus sets and varied presentation times. We would expect an effect of enhanced information processing for phobic stimuli that clearly differ in their low-frequency information (cf. Fig. 10) and for phobic stimuli that are presented for extended periods of time.

5. Conclusions

In our study, we tested information processing of ambiguous stimuli

in spider-fearful individuals. To this aim, we gradually morphed natural images of non-spiders and spiders and compared responses to these stimuli between a group of spider-fearful and non-anxious comparison participants in a perceptual and emotional rating task, a response priming task, and two go/no-go tasks. Replicating previous work (Haberkamp et al., 2013; Haberkamp & Schmidt, 2015), our findings show reliable effects of non-ambiguous phobic stimuli on information processing in spider-fearful individuals, in perceptual and emotional judgments, as well as in motor responses (group differences in target effects). Spider-fearful individuals tend to classify ambiguous morphed stimuli as spiders rather than non-spiders and show stronger negative emotions to them compared to neutral stimuli, even with very short presentation times. However, we do not find modulations of motor responses for briefly presented phobic or ambiguous stimuli (no group differences in priming effects and go/no-go responses). We suggest that these findings can be explained by the nature of response priming and go/no-go tasks that tap into early phases of visual processing, thereby relying on feedforward-mediated low-spatial-frequency information extracted via the fast, subcortical path to the amygdala.

Author note

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Appendix

Table A1

Results of the *Color Task*. Percentages of hits, correct rejections, false alarms, and misses for the different targets separately for both groups. 95% confidence intervals (CI) are based on bootstrapping. Note that due to data loss, conditions in the comparison group were not perfectly balanced so that hits and misses, as well as correct rejections and false alarms, do not add up to 50%.

	Spider Fear		Comparison	
	Frequency (%)	CI	Frequency (%)	CI
Non-spider targets				
Hits	48.4	[45.8, 50.8]	47.4	[44.8, 49.9]
correct rejections	48.1	[45.8, 50.7]	48.7	[46.2, 51.3]
false alarms	1.9	[1.2, 2.6]	2.5	[1.8, 3.3]
misses	1.6	[1.0, 2.3]	1.4	[0.9, 2.0]
Morph 1 targets				
hits	48.9	[46.5, 51.3]	47.6	[45.1, 50.1]
correct rejections	48.1	[45.7, 50.6]	48.8	[46.4, 51.2]
false alarms	1.9	[1.3, 2.6]	2.5	[1.8, 3.4]
misses	1.1	[0.6, 1.7]	1.1	[0.5, 1.6]
Morph 2 targets				
hits	49.4	[47.3, 52.0]	47.9	[45.3, 50.4]
correct rejections	48.5	[46.1, 50.8]	49.6	[47.1, 52.1]
false alarms	1.5	[0.9, 2.1]	1.8	[1.1, 2.5]
misses	0.6	[0.3, 0.9]	0.7	[0.3, 1.2]
Morph 3 targets				
hits	49.2	[46.8, 51.7]	48.0	[45.3, 50.5]
correct rejections	48.1	[45.6, 50.4]	49.7	[47.2, 52.3]
false alarms	1.9	[1.3, 2.6]	1.6	[0.9, 2.2]
misses	0.8	[0.4, 1.3]	0.7	[0.3, 1.2]
Spider targets				
hits	49.5	[47.1, 52.0]	47.9	[45.3, 50.5]
correct rejections	47.6	[45.2, 49.9]	49.5	[46.9, 52.0]
false alarms	2.4	[1.6, 3.1]	1.8	[1.1, 2.5]
misses	0.5	[0.2, 0.9]	0.8	[0.3, 1.4]

Table A2

Results of the *Spider/Non-spider Task*. Percentages of hits, correct rejections, false alarms, and misses for non-spider and spider targets separately for both groups. 95% confidence intervals (CI) are based on bootstrapping.

	Spider Fear		Comparison	
	Frequency (%)	CI	Frequency (%)	CI
Non-spider targets				
hits	43.7	[41.3, 46.2]	48.2	[45.7, 50.6]
correct rejections	41.7	[39.3, 44.3]	46.3	[44.1, 48.8]
false alarms	8.3	[7.0, 9.6]	3.7	[2.8, 4.6]
misses	6.3	[5.2, 7.4]	1.8	[1.2, 2.5]
Spider targets				
hits	43.9	[41.4, 46.4]	48.7	[46.1, 51.2]
correct rejections	42.8	[40.2, 45.3]	46.6	[44.3, 49.2]
false alarms	7.2	[6.0, 8.6]	3.4	[2.6, 4.3]
misses	6.0	[4.8, 7.2]	1.3	[0.8, 1.8]

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