Enhanced information processing of phobic natural images in participants with specific phobias

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Publishing note

Experiment 1 (Chapter 2) is already published in Acta Psychologica (see Haberkamp, A., Schmidt, F., & Schmidt, T. (2013). Rapid visuomotor processing of phobic images in spider-and snake-fearful participants. *Acta psychologica*, *144*(2), 232-242.). The method and results part (Section 2.2 and 2.3) of Experiment 1 mainly correspond with the respective manuscript. However, I adjusted the introduction and discussion of the experiment (Section 2.1 and 2.4) to incorporate them in the present dissertation. Reprint permission was granted by the respective copyright owner. The manuscripts for Experiment 3 (Chapter 4; Reference: Haberkamp, A. & Schmidt, T. (submitted). Information processing is enhanced in blood-injury-injection fear: Evidence from a response priming study. *Manuscript submitted for publication.*) and 4 (Chapter 5; Reference: Haberkamp, A., Schmidt, T., & Weiß, K. (submitted). Spiders capture attention: A prior-entry-effect for phobia-relevant stimuli. *Manuscript submitted for publication.*) are currently submitted. In an analogous manner, the respective method and results parts (Section 4.2, 4.3, 5.2, and 4.3) mainly correspond with the respective manuscripts. The introductions and discussions (Section 4.1, 4.4, 5.1, and 5.3) are adjusted to meet the requirements of the present thesis. Sincere thanks are given to my supervisor Thomas Schmidt and my co-authors Katharina Weiß and Filipp Schmidt for their help and contributions to the published and submitted manuscripts.

Contents

Abstract

From an evolutionary point of view, it can be assumed that visual processing and rapid detection of potentially dangerous stimuli in the environment (e.g., perilous animals) is highly adaptive for all humans. In the present dissertation, I address three research questions; (1) Is information processing of threatening stimuli enhanced in individuals with specific phobias? (2) Are there any differences between the different types of phobia (e.g., spider phobia vs. snake phobia)? (3) Is the frequently reported attentional bias of individuals with specific phobias - which may contribute to an enhancement in information processing – also detectable in a prior entry paradigm? In Experiments 1 to 3 of the present thesis non-anxious control, spider-fearful, snake-fearful, and blood-injection-injury-fearful participants took part in the study. We applied in each experiment a response priming paradigm which has a strong theoretical (cf. *rapid-chase theory;* Schmidt, Niehaus, & Nagel, 2006; Schmidt, Haberkamp, Veltkamp et al., 2011) as well as empirical background (cf. Schmidt, 2002). We show that information processing in fearful individuals is indeed enhanced for phobic images (i.e., spiders for spider-fearful participants; injuries for blood-injury-injection(BII)-fearful individuals). However, we found marked differences between the different types of phobia. In Experiment 1 and 2 (Chapter 2 and 3), spiders had a strong and specific influence in the group of spider-fearful individuals: Phobic primes entailed the largest priming effects, and phobic targets accelerated responses, both effects indicating speeded response activation by phobic images. In snake-fearful participants (Experiment 1, Chapter 2), this processing enhancement for phobic material was less pronounced and extended to both snake and spider images. In Experiment 3 (Chapter 4), we demonstrated that early information processing for pictures of small injuries is also enhanced in BII-fearful participants, even though BII fear is unique in that BII-fearful individuals show opposite physiological reactions when confronted with the phobic stimulus compared to individuals with animal phobias. These results show that already fast visuomotor responses are further enhanced in spider- and BII-fearful participants. Results give evidence that responses are based on the first feedforward sweep of neuronal activation proceeding through the visuomotor system. I propose that the additional enhancement in spider- and BII-fearful individuals depend on a specific hardwired binding of elementary features belonging to the phobic object in fearful individuals (i.e., effortless recognition of the respective phobic object via hardwired

neuronal conjunctions). I suggest that these hardwired conjunctions developed due to long-term perceptual learning processes. We also investigate the frequently reported attentional bias of phobic individuals and showed that this bias is detectable in temporal order judgments using a prior entry paradigm. I assume that perceptual learning processes might also strengthen the attentional bias, for example, by providing a more salient bottom-up signal that draws attention involuntarily. In sum, I conclude that (1) early information processing of threatening stimuli is indeed enhanced in individuals with specific phobias but that (2) differences between divers types of phobia exist (i.e., spider- and BII-fearful participants show enhanced information of the respective phobic object; though, snake-fearful participants show no specific information processing enhancement of snakes); (3) the frequently reported attentional bias of spider-fearful individuals is also detectable in a prior entry paradigm.

Outline of the present thesis

The present thesis aims to give further insight into the processing of threat-relevant stimuli. More specifically, I am interested in how phobic stimuli[1] (i.e., threat-relevant stimuli which are particularly feared by someone with a specific phobia) are processed by participants with a specific phobia (i.e., a subgroup of anxiety disorder accompanied by an irrational fear of specific objects or situations) compared to non-anxious control participants. In the four experiments introduced in this thesis, we applied different methods (i.e., a response priming and a prior entry paradigm) to study the speed of information processing and the attentional biases in phobic and control participants. We investigated three different kinds of specific phobias: spider, snake and blood-injury-injection (BII) phobia. That approach enables us on the one hand to compare and on the other hand to differentiate between the different types of specific phobias.

Two main reasons motivated the present research. Firstly, three major research gaps exist that we try to fill in with our experiments. To begin with, it is not fully understood on which neurophysiological mechanism enhanced information processing is based. The widespread assumption is that the amygdala is crucially involved. However, the results of our response priming study challenge that assumption (Experiment 1/Chapter 2; for a replication of the results see Experiment 2/Chapter 3). Second, even when the underlying mechanisms of enhanced information processing are unclear, it is widely accepted that this enhancement exists in individuals with animal phobia. But, only few studies investigated early information processing (and attentional bias respectively) in the group of blood-injury-injection phobics. Hence, we conducted a response priming study to fill that gap (Experiment 3/Chapter 4). Third, it is unknown whether the attentional bias towards phobic and threat-relevant stimuli also influence the temporal perception of the same. Therefore, we conducted a prior entry paradigm to test this assumption in Experiment 4 (Chapter 5). Most importantly, the applied research methods are well understood, empirical tested by numerous studies (e.g., Schmidt & Schmidt, 2009; Weiß & Scharlau, 2012), and are based on theoretical considerations

[1] Note that the expression *threat-relevant* refers to objects or situations which are assumed to be aversive or threatening in general but not specifically feared. The term *phobic* is used in case an objects or situation is specifically feared by a person. For example, spiders are phobic to spider-fearful individuals. *Neutral* objects (e.g., mushrooms) are assumed to elicit no negative emotion at all.

(e.g., *rapid-chase theory;* Schmidt et al., 2006). Thus, I believe that our results contribute meaningfully to each of the current discussions in the scientific community.

Secondly, specific phobias have serious health and social implication for individuals suffering from them. For example, BII-fearful individuals frequently avoid necessary medical procedures (Kleinknecht & Lenz, 1989; Öst, 1992) which in turn can be fatal in extreme cases (Hamilton, 1995). Thus, more effective treatments are important endeavors. I suppose that basic research on specific phobias – as conducted in the present thesis – is crucial to achieve that goal. For instance, our results show that individuals with different phobias respond divers to the phobic stimulus material. Spider-fearful individuals show a very specific response pattern towards spiders. However, snake-fearful individuals show a more general information enhancement to threat-relevant stimuli per se (i.e., they respond faster to snakes but also to spiders). Accordingly, these results indicate that spider phobia should be treated very specifically focusing on the specific fear for spiders. In contrast, snake-fearful participants show a general hypervigilance pattern. Therefore, the treatment of snake phobia should focus on fear in general. In sum, the research gaps described above and the importance of basic research for the understanding and treatment of anxiety disorders are the rationale for the present thesis.

1. General introduction

Anxiety disorders are the most prevalent class of clinical disorders among German adults with a *12-month prevalence* (i.e., frequency of affected individuals within a year) of 14.5 percent (Jacobi et al., 2004). They include specific diagnoses of panic disorder, agoraphobia, social phobia, obsessive-compulsive disorder (OCD), post-traumatic stress disorder (PTSD), acute stress disorder, generalized anxiety disorder (GAD), substance-induced anxiety disorder, anxiety disorder not otherwise specified (NOS), as well as specific phobias (e.g., fear of spiders) (DSM-IV-TR, American Psychiatric Association, APA, 2000). In addition to feelings of fear or concern, people with anxiety disorders suffer from somatic symptoms, like increased heart rate, dizziness, chest tightness (Barlow, 2002), muscle tension, hyper-vigilance, sleep disturbance, and fatigue (Wetherell, Lang, & Stein, 2006). Anxiety disorders are also characterized by specific cognitive characteristics including feelings of risk and danger and a sense of diminished coping abilities in anxiety-related situations (Beck, Emery, & Greenberg, 1985).

These cognitive particularities also affect basic processes of perception and information processing; for instance, ambiguous and even neutral visual stimuli are interpreted as threat-relevant by people suffering from anxiety disorders (Wetherell et al., 2006). Moreover, they attend to threat-relevant stimuli more frequently compared to non-anxious individuals. This attentional bias (i.e., attention is automatically and involuntarily drawn towards threat-relevant stimuli) has been demonstrated in several recent studies (Fox, Griggs, & Mouchlianitis, 2007; Mogg & Bradley, 2006; Rinck & Becker, 2006; for reviews see Mathews & MacLeod, 2005; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007). When threat-relevant stimuli are present, it generally leads to an increased distractibility and poorer task performance (e.g., Devue, Belopolsky, & Theeuwes, 2011). Because this bias in information processing is of special interest for the present thesis, it will be addressed in detail in Section 1.5. “Attentional biases in specific phobias”. The present thesis will focus on one major class of anxiety disorders, namely on *specific phobias.*

Specific phobias - the name stems from the Greek God of war Phobos who sent Ares into the enemy's camp to spread fear and terror - are defined as extremely intensive and persistent reactions of fear which are caused by *specific situations* or *objects*.

Depending on the situation or object of fear, different forms of specific phobias are distinguished (e.g., spider phobia or blood-injury-injection phobia). People with phobias try to *avoid* these situations or objects, which might in fact result in the permanent maintenance of the specific phobia: although avoidance reduces fear for the short term, it also prevents sufficiently long exposure to the threat-relevant stimulus to unlearn the initial fear response (Rinck & Becker, 2006).

Note that there exists a high variability in normal fear reactions towards threat-relevant objects or situations in people without specific phobia as well as a high variability in the fear reactions of phobic individuals. To judge the clinical relevance of a given fear, a set of clearly defined criteria exist which will be discussed in the next section.

1.1. Diagnostic criteria for specific phobias

In Germany, a total of 8 percent of the citizens develop some sort of specific phobia in the course of their life, with women being affected twice as often as men (Wittchen, 1986). Thus, this class of psychological disorder poses a major health issue. I propose that basic research on specific phobias helps to improve treatments of the same.

Specific phobias are usually assessed by one of the two most widespread systems; the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR, American Psychiatric Association [APA], 2000) - which is mostly used in the United States and is the gold standard in scientific publications - and the *International Statistical Classification of Diseases and Related Health Problems* (ICD 10; Dilling, Mombour, & Schmidt, 2000) - which is mostly used by European psychologists and psychiatrists. In the following, I list the diagnostic criteria for specific phobias according to the DSM-IV-TR (APA, 2000).

"Diagnostic criteria for specific phobia (300.29)

A) Marked and persistent fear that is excessive or unreasonable, cued by the presence or anticipation of a specific object or situation (e.g., flying, heights, animals, receiving an injection, seeing blood).
B) Exposure to the phobic stimulus almost invariably provokes an immediate anxiety response, which may take the form of a situationally bound or

situationally predisposed panic attack. Note: In children, the anxiety may be expressed by crying, tantrums, freezing, or clinging.

C) The person recognizes that the fear is excessive or unreasonable. Note: In children, this feature may be absent.

D) The phobic situation(s) is avoided or else is endured with intense anxiety or distress.

E) The avoidance, anxious anticipation, or distress in the feared situation(s) interferes significantly with the person's normal routine, occupational (or academic) functioning, or social activities or relationships, or there is marked distress about having the phobia.

F) In individuals under age 18 years, the duration is at least 6 months.

G) The anxiety, panic attacks, or phobic avoidance associated with the specific object or situation are not better accounted for by another mental disorder, such as obsessive-compulsive disorder (e.g., fear of dirt in someone with an obsession about contamination), post-traumatic stress disorder (e.g., avoidance of stimuli associated with a severe stressor), separation anxiety disorder (e.g., avoidance of school), social phobia (e.g., avoidance of social situations because of fear of embarrassment), panic disorder with agoraphobia, or agoraphobia without history of panic disorder" (DSM-IV-TR, APA, 2000, p. 449-450).

Besides these general criteria, specific phobias are classified in several subtypes due to differences in symptoms, epidemiology, onset of phobia, and prognosis: animal type (e.g., spider and snake phobia), natural environment type (e.g., heights, storms, water), blood-injection-injury type, situational type (e.g., airplanes, elevators, enclosed places), and other type (e.g., phobic avoidance of situations that may lead to choking, vomiting, or contracting an illness; in children: avoidance of loud sounds or costumed characters; Hamm, 2006).

In the daily routine of mental health care and clinical research, several diagnostic instruments are at hand to diagnose specific phobias in patients or participants. For example, in our experiments, we firstly used a semi-structured interview which is based on the DSM-IV-TR classification system and provides important information about the clinical relevance of the particular specific phobia ("Diagnostisches Interview bei

psychischen Störungen" DIPS, Schneider & Margraf, 2006). Furthermore, self rating questionnaires are conducted to measure the severity of the participant's symptoms and are available for a wide range of different specific phobias (e.g., the 'Snake Questionnaire' SNAQ by Klorman, Weerts, Hastings, Melamed, & Lang, 1974; or the German questionnaire 'Fragebogen zur Angst vor Spinnen [Questionnaire of spider fear]' FAS by Rinck et al., 2002).

Yet, there are persons who develop a specific phobia whereat other persons in the same situation with the similar life experiences seem to be immune to acquire that fear. So, what causes these interindividual differences in the acquisition of fear and are there protective factors that prevent the development of specific phobias? Several behavioral and cognitive theories try to explain the origin of specific phobias and in that course name different factors which account for individual differences.

1.2. A history of models on fear acquisition

In this section, I overview the most influential theories on the origin of specific phobia. Three of the five discussed models make predictions about how threat-relevant stimuli are processed in humans while different explanations sometimes overlap with one another. The different assumptions on enhanced information processing will be discussed in section 1.4. "Enhanced information processing in specific phobias". The Classical Conditioning Model can be assumed to be the starting point of the scientific examination of specific phobias. All subsequent models or theories are either extensions or arose as a critique of the original model. Therefore, I will start the historical overview with the Classical Conditioning Model and discuss the successive models and theories with respect to the limitations of the original model.

1.2.1. The classical conditioning model

Classical conditioning has its origin in animal research studies and is strongly influenced by the work of John B. Watson in the early 20th century (e.g., Watson & Rayner, 1920). In their famous study, Watson and Rayner (1920) aimed to investigate the origin of specific phobias by conditioning a 9-month old child named Albert. According to the authors, Albert was an emotionally stable child, raised in an hospital environment, and one of the best developed babies in the group. In a baseline

experiment, they confronted Albert successively and for the first time “with a white rat, a rabbit, a dog, a monkey, with masks with and without hair, cotton wool, burning newspapers, etc.” (Watson & Rayner, 1920, p. 2). Albert showed no fear of any of the items. To test if loud sounds cause a fear reaction in Albert, the experimenter stroke a hammer upon a steel bar. They wrote:

> “One of the two experimenters caused the child to turn its head and fixate her moving hand; the other, stationed back of the child, struck the steel bar a sharp blow. The child started violently, his breathing was checked and the arms were raised in a characteristic manner. On the second stimulation the same thing occurred, and in addition the lips began to pucker and tremble. On the third stimulation the child broke into a sudden crying fit. This is the first time an emotional situation in the laboratory has produced any fear or even crying in Albert” (Watson & Rayner, 1920, p. 2).

When Albert was in the age of 12-months, the authors placed a rat close to Albert and he was allowed to play with it. In line with the findings of the baseline, Albert experienced no fear towards the rat. In the following, the authors stroke the steel bar with a hammer behind Albert's back. Albert responded to the sound by showing fear and crying. After several trials, they placed the rat close to Albert without presenting the noise. However, Albert showed fear symptoms once the rat appeared. Evidently, the baby had learned the association between the white rat and the loud noise. In conditioning terms, the noise was an *unconditioned stimulus* (US) which elicited in Albert an *unconditioned response* (UR) of fear. The rat represented a *conditioned stimulus* (CS) – a formerly neutral stimulus that became associated with the noise and, therefore, triggered fear responses in Albert. The associated fear of Albert with the rat represent the *conditioned response* (CR). 5 days later, the authors confronted Albert with other animals like rabbits, dogs and objects like fur coats and Albert also showed fear symptoms. The authors concluded that Albert's conditioned fear of the rat also generalized to other furry animal and objects. The experiment demonstrate one way specific phobias might develop. However, there is no evidence that Albert indeed developed a specific fear of rats or furry animals or objects. 10 days after the initial

combination of the rat and the noise, Albert was again confronted with the rat. He started to crawl away but there was no crying.

According to Harris (1979), the study by Watson and Rayner was misinterpreted by many introductory-level textbooks for graduate students ranging from small misinterpretations including Albert's name, his age, the spelling of Rayner's name, and whether the conditioned stimulus was a rat or a rabbit to more significant interpretations including Albert's life and alleged fear after the experiment (for example of fur pelts, a man's beard, a white furry glove, the fur coat of his mother, or even a teddy bear). Additionally, happy endings had been invented by including the fact that Watson 'reconditioned' Albert after the experiment (Harris, 1979).

Beside the misinterpretations, the study of Watson and Rayner (1920) should not be over-interpreted in favor of the classical conditioning account due to various methodological reasons. First, the study included merely one single participant. Second, as stated above, it is unclear whether Albert indeed developed a specific phobia of rats and whether a post-experimental generalization effect occurred. Third, emotions were not reliably assessed (cf. Sherman, 1927). Fourth, the experiment confound classical and instrumental conditioning. At least in three trails the loud was mad when Albert was actively touching the rat or reaching out for the rat (Larson, 1978; Reese & Lipsitt, 1970). Finally, the experiment can be considered as highly unethical and replications are not realizable today. Harris (1979) commented the study by writing in his article: “It may be useful for modern learning theorists to see how the Albert study prompted subsequent research [...], but it seems time, finally, to place the Watson and Rayner data in the category of “interesting but uninterpretable results” (p. 158).

Despite the high face validity of the classical conditioning model, clinicians often fail to discover the specific conditioning events which caused the specific phobia (Herbert, 1994). For instance, Öst (1992) found that 17 percent of blood or injection phobics did not recall any specific cause for their disorder. Therefore, alternative explanation for the acquisition of fear emerged.

1.2.2. Social learning theory

To begin with, researches realized that the acquisition of fear could be modified by family members' particularly by parents' behavior (e.g., Rachman, 1978). These findings were linked to Bandura's *Social Learning Theory* and *Modeling* (Bandura,

1977; Bandura & Rosenthal, 1966). Bandura's approach indicates that learning takes place in a social context. Like other social behavior, fear can be primarily learned through observation and imitation. Bandura and Rosenthal (1966) conducted a study in which a participant watched an experimenters' confederate who pretended being shocked by electricity each time a buzzer sounded. After watching several episodes, the participants themselves experienced fear whenever they heard the buzzer. Additionally, in Cook and Mineka's (1989) study rhesus monkeys watched a monkey model behaving fearfully to toy snakes and toy crocodiles. As a result, these monkeys acquired fear of the respective toys. Moreover, the probability increases that children develop a specific fear towards an object (e.g., a spider) or situation (e.g., air travel) if their parents show fear of the respective object or situation. Correspondingly, children with specific phobias frequently report that they have observed their parents reacting fearful in the same or similar situations (Mineka & Zinbarg, 2006).

However, social learning can also lead to a significant reduction in fear. Bandura and Menlove (1968) conducted a desensitization study in which dog-fearful children watched either a movie in which a model interacted non-anxiously with a single dog or a movie in which a variety of models interacted non-anxiously with numerous dogs varying in race. In both groups, children's avoidance behavior was significantly reduced. Subsequent, these aspects were integrated and extended the assumptions of the classical conditioning model (Coelho & Purkis, 2009).

1.2.3. Preparedness

Additionally, the Classical Conditioning Model implies that every arbitrary stimulus may become fearsome by conditioning. But, phobias are mostly connected with just a limited number of stimulus categories (e.g., spiders, snakes, heights, blood, thunderstorms, and not, e.g., flowers, cf. Cook & Mineka, 1989). Therefore, the concept of *preparedness* (Garcia & Koelling, 1967, see also Mineka & Zinbarg, 2006) was added to the model. In this perspective, individuals are, in varying degrees, biologically prepared to develop a phobia when confronted with stimuli that are related to survival. Frequently, these stimuli include spiders, but only 200 species of spiders out of 30,000 are potentially lethal to humans (Diaz, 2004). In contrast, mushrooms which are not regarded as fearful stimuli can indeed cause poisoning in humans (Kotwica & Czerczak, 2007). Alone in the United States, 100 species of poisonous mushrooms exist (Lincoff

& Mitchel, 1977). Taken together, mushrooms present a greater hazard to humans than spiders (Coelho & Purkis, 2009) and yet humans do not demonstrate a fear of mushrooms.

However, it should be considered that biological preparedness might be related strictly to stimulus categories that require actions such as *fight* (i.e., aggressive and combative behavior) and *flight* (i.e., fleeing potentially threat-relevant situations). In other words, the person's internal physiological state changes confronted with threat. These changes prepare the person for possible 'fight or flight' reactions (Cannon, 1929). These actions are relevant to react to the sudden appearance of animals. However, biological preparedness might not be necessarily related to the actual danger of the respective stimuli but to the necessity of fight and flight reactions.

However, the classical conditioning model assumes not only that every arbitrary stimulus can become fearsome by fear conditioning, but that this link can be learned by every animal or person. That is, genetic influences are not considered in the original model. Two recent models acknowledge the influence of heritability and evolution, respectively; the *Non-Associative Model* and the *Fear Module Theory*.

1.2.4. The non-associative model

The non-associative model assumes that humans will develop certain fears to a specific set of evolutionary relevant stimuli without any associative learning (e.g., classical conditioning), social learning or vicarious information. The approach suggest that individuals who experience some fear towards dangerous objects or situations are favored via Darwinian natural selection compared to individuals who initially have to acquire fear through either direct or indirect learning processes.

Menzies and Clarke (1993) asked the parents of 50 children with diagnosed water phobia to name the most important factor which led to the development of their child's phobia. Importantly, only one parent could recall an event of classical conditioning while more than 50 percent of the parents reported that their child's fear of water had always been present. However, the main disadvantage of the non-associative model is that it does not account for the complexity of fear acquisition by including all relevant factors (e.g., the individual vulnerability to fear, the level of development of the child, the previous experiences with uncontrollable events, or the initial beliefs about a stimulus). Furthermore, retrospective recall carries certain problems. According to

Nisbett and Wilson (1997), verbal reports are not sufficient to reveal causal processes. That point is even more problematic given that learning and conditioning can happen outside of awareness (Öhman & Soares, 1994). Furthermore, human memory is unstable; it can easily be changed, for example, based on experiences (Loftus, 2004). This is especially true for children's memories (Brainerd & Mojardin, 1998). Finally, the non-associative model hypothesizes a strong role of heritability in the development of phobias (Coelho & Purkis, 2009); however, a study of twins did not support this notion (Kendler, Neale, Kessler, Heath, & Eaves, 1992).

1.2.5. The fear module theory

Öhman and Mineka (2001) proposed their idea of a module for fear acquisition which is based on the concept of evolutionary adaptiveness. In contrast to the Non-associative theory, direct contact with the potentially threat-relevant stimulus is a precondition for fear acquisition. But, similar to the assumptions of this theory, particular stimuli exist which are evolutionarily relevant and which also elicit fear more easily compared to potentially dangerous but contemporary stimuli (e.g., guns) (Fox et al., 2007). According to Öhman and Mineka (2001), danger existed in the early mammalian environment in the form of hunting predators, falling objects, floods, and thunderstorms. Plausible reactions to these events were escape and avoidance of the potentially threat-relevant situations or locations. To escape potential danger, mammals needed at least a perceptual system to identify the threat and a reflexively wired motor system to enable flight. Both systems had to be connected in a way that increases effectiveness and avoids stereotyped behavior, so that depending on the circumstances different response options like freeze, escape, or attack can be chosen. The authors assume that this connection is made by a central motive state, which is commonly known as fear (e.g., Öhman, 1993).

From an evolutionary perspective, these learned survival-relevant relationships would become a factor in the process of natural selection. Based on these assumptions, the authors developed a new concept of an evolutionary fear model with four important characteristics. (1) The fear module is preferentially activated for defensive behavior by

stimuli which are evolutionarily fear-relevant.[2] (2) Its activation is automatic and fast. (3) If fear is once initiated it is relative independent of cognitive control. (4) The fear module is based on a neural circuitry which is centered on the amygdala. In contrast to classical conditioning models, the fear module theory can explain why an uneven distribution of fear stimuli exists, that means, why people develop a specific phobia of spiders and snakes but do not develop a specific phobia of weapons and motorcycles. Furthermore, the theory explains the fact that evolutionarily fear-relevant stimuli are easier to train in the laboratory compared to evolutionarily fear-irrelevant stimuli.

However, the role of the amygdala had been questioned in recent studies (e.g., Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Phillips et al., 2004; Piech et al., 2010; Tsuchiya, Moradi, Felsen, Yamazaki, & Adolphs, 2009). The discussion about the role of the amygdala per se and particularly in enhanced information processing is of utmost importance for the present thesis and, therefore, will be reviewed in more detail in Experiment 1 (Chapter 2) and Section 6.2. "Enhanced information processing and the amygdala network". Furthermore, the fear module theory does not account for interindividual differences in fear acquisition. For example, early exposure to a particular stimulus can impede a subsequent aversive conditioning even if it is evolutionarily fear-relevant – e.g., non-traumatic experiences with spiders or snakes can prevent the acquisition of the respective fears (Coelho & Purkis, 2009). The latter point is acknowledged by cognitive models of fear learning which emphasize the importance of beliefs and expectancies. Therefore, they provide a theoretical background to explain interindividual differences beyond the assumptions of the original classical conditioning model in which cognitive factors did not play a role.

1.2.6. Cognitive models

Some authors emphasize that conditioning is a cognitive process (Thorpe & Salkovskis, 1995). Indeed, humans learn that two events (i.e., an aversive event and a neutral event) occur simultaneously in time and, hence, become connected and produce the same (emotional) response. Consequently, the authors assume that expectations play an important role (Tolman, 1949). For example, Davey (1995) argues that participants

[2] Note that anxiety is mostly referred to as being an unpleasant, vague emotional state whereas fear is the emotional reaction to a specific object or situation. If fear of a concrete object or situation is irrational and inappropriate we refer to it as a specific phobia.

may have certain expectations about the relationship between threat-relevant stimuli and aversive events. Specifically, they may assume that fear-relevant stimuli are more often followed by an aversive event (e.g., electric shocks) compared to fear-irrelevant stimuli. Accordingly, participants would report that fear-relevant stimuli were more often paired with aversive events even if this was not true. In one of their early experiments, Öhman and colleagues (Öhman, Eriksson, Fredriksson, Hugdahl, & Olofsson, 1974) investigated habituation processes by presenting participants with putative aversive pictures of snakes and spiders or putative neutral pictures of houses. The first emotional orienting response triggered by the pictures was measured by electrodermal electrodes (i.e., it is assumed that skin conductance can be used as a measurement of autonomic arousal and fear, respectively). They found that participants habituated faster to neutral fear-irrelevant pictures (in that case the orientation responses were less strong). In a subsequent experiment, the authors applied electric shocks before the experiment and threatened that more shocks would be given during the experiment. In that case, the differences in skin conductance increased dramatically (i.e., responses to aversive pictures were four times as strong compared to neutral pictures). The authors concluded from their results that spiders and snakes are biologically prepared stimuli and, therefore, easier to condition.

Supporter of the cognitive approach would argue that the participants expected that aversive pictures would more likely to be followed by shocks compared to neutral pictures. Therefore, their arousal increased after the presentation of spider and snake images. According to Coelho and Purkis (2009), the mentioned bias seems to be stronger for *phylogenetic (*i.e., evolutionarily acquired) compared to *ontogenetic* (i.e., acquired within a lifespan) fear-relevant stimuli. One major point of critique of the cognitive models is that, in line with the Fear Module Theory, fear can be elicited in an automatic fashion and mostly independent from the participant's cognition. Still, Davey (1995) argues that the repeatedly demonstrated information processing bias of threat-relevant stimuli (e.g., Anderson & Phelps, 2001; Öhman, Flykt, & Esteves, 2001; Piech et al., 2010) is based mainly on expectations rather than phylogenetic predispositions.

Summing up, the popular *Classical Conditioning Model* assumes that the acquisition of fear in specific phobia is mostly due to aversive events in the past leading

to conditioned fear responses. This accounts is further expanded by the *Social Learning Theory* and the concept of *Preparedness*. Secondly, the *Non-Associative Theory* states that the development of specific phobias is possible without any classical conditioning experiences. In contrast, fear responses should be hereditary via Darwinian natural selection. Thirdly, the *Fear Module Theory* proposes that the concept of evolutionary adaptiveness plays the most important role in the acquisition of fear and the corresponding responses. And finally, *Cognitive Models* emphasize the role of expectations in the origin of specific phobias and enhanced information processing. Most models discussed here assume that threat-relevant stimuli are processed faster than neutral ones, either due to emotional, evolutionary, or cognitive factors. However, it seems inadequate to discuss them separately. Davey (1995) acknowledged the fact that, for example, expectation bias and evolutionary predisposition may coexist. More recent models explicitly try to integrate different factors. For instance, Mineka and Zinbarg (2006) used elements of learning theories as well as of the preparedness model to describe the etiology and maintenance of anxiety disorders. Thus, it seems that natural selection as well as everyday life experiences can play a role in the acquisition of fear. While phylogenetic evolution may create general predispositions, ontogenetic learning can contribute to the individual occurrence of a specific fear. To my knowledge, no empirical study exists which aimed to truly differentiate between the current theories of fear acquisition. However, numerous studies give evidence or challenge the debated models (cf. Coelho & Purkis, 2009).

In addition to theories on the origin of specific phobias, several theories are engaged in explaining the biological foundations of fear reactions, in the central as well as the peripheral system. The next paragraphs will briefly overview the main theories and most recent findings in the neurobiology of anxiety.

1.3. Neurobiology of anxiety

The brain structure mostly associated with fear is the *amygdala,* which is one of the subcoritcal structures of the brain and receives input from the thalamus as well as the cortex. The amygdala controls freezing, blood pressure, and stress hormones by projections to the periaqueductal gray, lateral hypothalamus, periventricular hypothalamus, and the reticulopontis caudalis (which is a critical component of the

startle reflex, i.e., protecting the eye by eye blink; LeDoux, 1995). Thus, according to LeDoux (1995), the amygdala is by far the most important brain structure for human fear responses. Later, other brain structures were described that are involved in anxiety. Firstly, the locus coeruleus regulates arousal and attention. Secondly, the hippocampus that encodes emotionally relevant information, and, thirdly, the prefrontal cortex that plays an important role in modifying behavior towards threat-relevant stimuli (Wetherell et al., 2006).

Gray emphasized different brain structures in emotional responses and proposed a model which includes a behavioral inhibition system (BIS), a behavioral approach system (BAS), and a fight-flight system (e.g., Gray & McNaughton, 1996). In his view, the BIS consisting of the septal area, hippocampus, and the Papez circuit suppresses behavior and directs attention to stimuli which are new or potentially followed by non-reward or punishment. According to Gray, fear or anxiety is caused by an overly reactive BIS. In contrast, the BAS which consists of the medial forebrain bundle is activated in situations when punishment is unlikely and reward likely. Finally, the fight-flight system, which is composed of the central periaqueductal gray, the medial hypothalamus, and the amygdala, prepares aggressive defense reactions or escape in potentially dangerous situations.

Also, different neurotransmitters are involved in fear reactions. I will briefly describe the five most important neurotransmitters and their properties. Firstly, the release of γ-aminobutyric acid (GABA) opens neuronal chloride channels which lead to a decreased responsiveness of the nerve cells. Knock-out studies with mice were conducted to investigate the influence of the $GABA_A$ receptors on anxiety. They showed that dysfunctions of these receptors led to a reduced benzodiazepine binding in the hippocampus and cerebral cortex which in turn elicited increased behavioral reactivity to aversive stimuli in these knock-out mice (Crestani et al., 1999; cf., Nemeroff, 2003). Secondly, the noradrenergic system plays an important role in arousal regulation and improves the signal-to-noise ratio for relevant events in the environment (Wetherell et al., 2006). Thirdly, a decreased release of serotonin leads to an increased responsiveness to punishment and fear. However, different serotonin receptors[3] seem to play different

[3] Note that fourteen different serotonine receptors exist which are classified into seven categories (ranging from $5HT_1$ to $5HT_7$; Andrade et al., 2013; Wesolowska, 2002).

roles in fear reactions: the presynaptic activation of the $5HT_{1a}$ receptor leads to a reduced fear reaction whereas the postsynaptic activation of the $5HT_{1a}$ receptor as well as the $5HT_{1b}$, $5HT_{1c}$, $5HT_{2a}$, $5HT_{2c}$ and $5HT_3$ receptors leads to an increased fear reaction reaction. Also, serotonin indirectly influences the noradrenergic and dopaminergic transmitter systems in which the latter system increases motivation and coping responses in threat-relevant situations. Fourthly, glutamate as an excitatory neurotransmitter plays an important role in the acquisition of memories and conditioned emotional responses. Finally, corticotropin-releasing hormone, which acts as a hormone as well as a neurotransmitter, activates most of the physiological sensations experienced in threat-relevant situations by activation of the hypothalamic-pituitary-adrenal axis.

Furthermore, several hormones are associated with fear reactions. Specifically, it was hypothesized that the release of epinephrine, norepinephrine, cortisol, and growth hormone is increased, and in men the release of testosterone is decreased in fear reactions (e.g., Noyes & Hoehn-Saric, 1998). However, an increase or a decrease of the respective hormones were not consistently demonstrated across studies (Wetherell et al., 2006). Though, the underlying neurobiological principals are crucial for the medication of anxiety disorders, but play an inferior role in the present thesis. Hereafter, I will mainly focus on the neurophysiological mechanisms of anxiety (i.e., in term of neuronal structures; cf. Section 6.3.2. “The neural basis of perceptual learning”).

In the following sections, I focus on the aspect of specific phobias which are most relevant for the conducted experiments of the present thesis; (1) enhanced information processing in specific phobias and (2) attentional bias in specific phobias. Furthermore, I link these topics to the applied methods of response priming and prior entry.

1.4. Enhanced information processing in specific phobias

From an evolutionary point of view (cf. Section 1.2.3. “Preparedness”, 1.2.5. “The fear module theory”), it can be assumed that visual processing and rapid detection of potentially dangerous stimuli in the environment is highly adaptive for all humans. In addition, that ability should be further enhanced if the given stimulus (e.g., a spider) is interpreted as threatening by one individual (e.g., by a spider phobic) even if the same

stimulus is taken as harmless by another non-anxious individual. Empirical evidence indicates that the processing of threat-relevant objects is enhanced in the general population (Fox et al., 2000; Lipp & Waters, 2007; Öhman, Flykt et al., 2001; Williams, Moss, Bradshaw, & Mattinley, 2005; but see Tipples, Young, Quinlan, Broks, & Ellis, 2002) as well as in individuals with specific phobias, (Lipp & Waters, 2007; Öhman, Flykt et al., 2001) and other anxiety disorders (e.g., social anxiety: Eastwood et al., 2005; Gilboa-Schechtman, Foa, & Amir, 1999).

For instance, in the study by Öhman, Flykt and colleagues (2001), non-anxious control participants, spider phobics, and snake phobics had to search for pictures of spiders or snakes in grid-pattern arrays of flower and mushroom pictures, and vice versa. Potentially threat-relevant pictures of spiders and snakes were found more quickly than neutral pictures by all three groups, with even faster performance in the two phobic groups. Furthermore, search times for spider and snake targets but not for neutral targets (flowers and mushrooms) were largely unaffected by the number of distractors (which normally increase response times in serial search tasks). That effect was further enhanced in phobic participants. These results suggest that detection of phobic pictures might be preattentive, such that pictures are not processed serially but simultaneously across the visual field (Treisman & Gelade, 1980). Even though such a "pop out" effect was not consistently found in more recent studies (Yiend, 2010) the evidence points to an information processing advantage for threat-relevant and phobic stimuli.

1.4.1. The response priming paradigm

Response priming is a well-understood method (Klotz & Neumann, 1999; Klotz & Wolff, 1995; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003; also cf. Schmidt, Haberkamp, & Schmidt, 2011) which enables us to determine whether accelerated processing of fear-relevant images is detectable at the earliest stages of observable behavior. Also, response priming has not been applied in this research field before. In response priming, participants have to classify a target stimulus into two response categories (e.g., animal vs non-animal), performing a speeded motor response. The target stimulus (e.g., a spider) is preceded by a prime stimulus triggering either the same response as the target (*consistent prime;* e.g., another spider) or the opposite response (*inconsistent prime;* e.g., a flower). If the prime is consistent, it speeds

responses to the target; if it is inconsistent, it slows responses. This *response priming effect* increases with increasing stimulus-onset asynchrony (SOA) between prime and target for SOAs up to 100 ms. In that case, the priming effects increase approximately linearly with SOA (Vorberg et al., 2003).

1.4.2. The rapid-chase theory of response priming

While response compatibility paradigms have been used before to study processing advantages for fear-relevant material, response priming has special properties that have not yet been confirmed for other paradigms. Firstly, many studies have confirmed that primes directly initiate the specific motor responses assigned to them (e.g., Leuthold & Kopp, 1998; Schmidt, 2002). Therefore, response priming effects are directly related to the visuomotor processes triggered by visual stimuli, and are sensitive to differences in visuomotor processing. Secondly, behavioral and electrophysiological evidence links response priming to visuomotor feedforward processing, because the earliest output of the motor system is controlled exclusively by the prime but is independent of all properties of the target. This was established for lateralized readiness potentials (Vath & Schmidt, 2007). More specifically, ERP-studies showed that the prime triggers relative increases in EEG negativity before response execution takes place and that these are stronger in the motor cortex contralateral to the responding hand (Eimer & Schlaghecken, 1998; Klotz, Heumann, Ansorge, & Neumann, 2007; Leuthold & Kopp, 1998; Vath & Schmidt, 2007; also cf. Schmidt, Haberkamp, & Schmidt, 2011).

These studies showed that initially the prime activates the response assigned to it, and then after the target-onset the response is controlled by the target (i.e., an inconsistent target would trigger the reaction opposite to the one elicited by the prime). Accordingly, if the prime has more time to influence the motor response, priming effects increase with prime-target SOA (for a mathematical model, see Vorberg et al., 2003). These effects can also be observed in the spatial domain. Goal-directed pointing responses are initially driven by the prime and in inconsistent cases mislead them in the wrong direction (Schmidt et al., 2006; Schmidt & Schmidt, 2009). In line with these results, in trials with inconsistent primes preceding the target the error rates increase compared to consistent trials.

In 2006, Schmidt and colleagues proposed *a rapid-chase theory of response priming*. They argue that enhanced information processing is based on sequential feedforward sweeps elicited by prime and target stimuli which activate the associated motor responses in strict sequence and without temporal overlap (cf. Schmidt, Haberkamp, Veltkamp et al., 2011). This theory predicts that the motor response should first be controlled exclusively by the prime signal and only later by the actual target signal. Because the theory assumes that the target's feedforward sweep cannot catch up with that of the prime, it makes the strong prediction that response priming effects should be fully present in the fastest responses and should not increase any further for longer response times. Consequently, we analyzed the fastest visuomotor responses (i.e., 2nd and 3rd deciles of the response time distribution) in Experiment 1 (Chapter 2) and 3 (Chapter 4) to show that the priming effects are already fully present in the fastest responses. These findings are consistent with such a simple feedforward model.

Another interesting aspect of response priming is its independence of visual awareness. That means even if the primes are not clearly visible - e.g., visibility can be altered by the temporal proximity with which prime and mask are presented – the priming effect typically remain the same (for double dissociations in metacontrast masking, cf. Albrecht, Klapötke, & Mattler, 2010; Mattler, 2003; Vorberg et al., 2003). This independence, which is only of theoretical importance for the present thesis, makes response priming a useful paradigm in the study of early visual processing.

1.5. Attentional biases in specific phobias

Attention in the sense of perceptual selectivity is adaptive and allows the agent to achieve goals and, therefore, promote survival. Attention can be modulated in two different ways: in a top-down manner (i.e., behavioral goals can modulate the processing of sensory input) or in a bottom-up manner (i.e., characteristics of the stimulus modulate attention; Yantis, 2000). The latter way of attentional modulation can be achieved by saliency of the item (e.g., Pashler, 1988; Theeuwes, 1992, for reviews see Corbetta & Shulman, 2002; Theeuwes, 2010). For example, a red circle embedded in an array of green circles may automatically capture attention. Also saliency can be modulated by the emotional significance of a stimulus. For instance, it might be highly

reasonable that attention is automatically drawn towards a perilous animal which hides in the woods (cf. Mathews & Mackintosh, 1998). In line with these findings, several studies found that threat-relevant stimuli (e.g., spiders or threatening faces) are preferentially attended compared to neutral stimuli (i.e., they are able to capture attention; e.g., Eastwood, Smilek, & Merikle, 2001; Fox et al., 2000; Mogg & Bradley, 2006; Koster, Crombez, Van Damme, Verschuere, & DeHouwer, 2004; Rinck & Becker, 2006; for reviews see Mathews & MacLeod, 2005; Bar-Haim et al., 2007).

Several studies indicate that the attentional bias has a time course where early attentional capture (e.g., Asmundson & Stein, 1994; Bradley, Mogg, White, Groom, & de Bono, 1999) by the fear-relevant stimulus is followed by deliberate avoidance (e.g., Pflugshaupt et al., 2005). Mogg and Bradley (2006) showed in a dot probe task that if spider or neutral pictures were presented for 200 ms, spider-fearful individuals showed a rapid attentional bias towards the spiders. At longer exposure times (500 ms and 2000 ms) no attentional biases for fear-relevant stimuli were found. Hence, I assume that the attentional bias towards threat-relevant stimuli is an early phenomenon which occurs within approximately the first half second of exposure (see also Rinck & Becker, 2006; for an alternative explanation of dot probe results, see Gerdes, Alpers, & Pauli, 2008).

1.5.1. The prior entry paradigm

As described in the previous chapter, evidence exits that threat-relevant stimuli are able to capture attention. One way to measure attentional capture is to use Temporal Order Judgments (TOJs) or Simultaneity Judgments (SJs). In these tasks, two stimuli are presented with varying stimulus onset asynchronies (SOAs). To measure attentional capture, attention in prior entry paradigms is typically either directed to one of the two stimuli (*cued trials*) or not (*uncued* trials). In TOJs, the participants indicate which of the two stimuli appeared first (or, occasionally, second; e.g., Scharlau, 2004; Shore, Spence & Klein, 2001; Yates & Nicholls, 2009). In SJs, the participants indicate if the two stimuli were presented simultaneously or not (e.g., Zampini, Guest, Shore, & Spence, 2005, Yates & Nicholls, 2011). The "law" of prior entry (e.g., Titchener, 1908) assumes that attended stimuli are perceived earlier than unattended stimuli. For example, if a square and a diamond are presented simultaneously and an observer attends the square, she will perceive the square before the diamond. Prior entry effects have been convincingly demonstrated within and between several modalities (vision:

e.g., Scharlau, 2007; Stelmach & Herdman, 1991; Weiß & Scharlau, 2011, 2012; audition: Kanai, Ikeda, & Tayama, 2007; tactile modality: Yates & Nicholls, 2009, 2011; bimodal prior entry: e.g., Spence et al., 2001, for a recent overview see Spence & Parise, 2010).

The prior entry effect is technically defined as the shift in the so-called *Point of Subjective Simultaneity* (*PSS*), that means, the temporal interval at which both order judgments are made equally often (TOJ) or simultaneous judgments are given most often (SJ). Typically, the PSS is shifted from near physical simultaneity in uncued trials to a temporal interval at which the uncued/unattended stimulus is presented first in cued trials.

Consistent with recent findings of attentional preference of threat-relevant stimuli (cf., Yiend, 2010), West, Anderson, and Pratt (2009) using a TOJ paradigm without cues demonstrated that angry faces capture attention compared to neutral faces, and that these stimuli showed visual prior entry. The prior entry paradigm is used in Experiment 4 (Chapter 5) to demonstrate that also spider stimuli are able to capture attention in spider-fearful participants.

1.6. Overview of the experiments

The goal of the present thesis is to give further insight into the early and rapid information processing of threat-relevant and phobic stimuli, respectively. Additionally, I am interested in whether threat-relevant and phobic stimuli are able to modulate attention. In the four experiments reported in this thesis, we applied different methods (i.e., a response priming and a prior entry paradigm) to study the speed of information processing (Experiment 1-3) and the attentional bias (Experiment 4) in fearful and control participants.

With the following experiments, I aimed to fill three main research gaps. First, it is not fully understood on which neurophysiological mechanism enhanced information processing is based. In Experiment 1 (Chapter 2), information processing of threat-relevant, aversive, and neutral natural images were measures in non-anxious control, spider-, and snake-fearful participants. The results show that threat-relevant stimuli are indeed processed faster than emotionally neutral stimuli in the experimental groups of spider- and snake-fearful participants. We observed distinct qualitative differences in

response patterns in all three groups. Therefore, meaningful conclusions about the neurophysiological processes of threat-relevant and phobic information can be drawn. I conclude that contrary to popular beliefs, enhanced information processing is rather due to perceptual learning processes than changes in amygdala activation.

In Experiment 2 (Chapter 3), we hypothesized that if our assumption of Experiment 1 is true, spider-fearful participants should not just respond faster to spider pictures (*Target Identification* task) but recognize shortly presented (masked) pictures of spider images better than non-anxious control participants (*Prime Identification* task). However, no such effect was observed. These results suggest that the categorization and identification of a stimulus are based on different processing mechanisms. That means stimuli can be classified during the first feedforward sweep of visuomotor processing, whereas the identification of stimuli requires recurrent feedback from separate cortical areas. I conclude that perceptual learning processes might enhance information processing of phobic stimuli. However, it does not seem to facilitate identification of these stimuli.

Second, even when the underlying mechanisms of enhanced information processing are unclear, it is widely accepted that this enhancement exists in the majority of individuals with animal phobia. But, only few studies investigated early information processing (and attentional bias, respectively) in the group of blood-injury-injection phobics, although they differ in important stimulus characteristics from other types of phobia (e.g., fainting when confronted with the phobic stimulus). Experiment 3 (Chapter 4) was conducted to measure rapid information processing of pictures of minor injuries compared to pictures of unharmed body parts in BII-fearful participants. Here we found, comparable to results in spider-fearful participants of Experiment 1 and 2 (Chapter 2 and 3), an advantage of phobic stimuli in response times in BII-fearful individuals.

Third, it is unknown whether the attentional bias towards phobic and threat-relevant stimuli also influence the temporal perception of the same. In Experiment 4 (Chapter 5), we investigated the role of attentional capture of phobic spider stimuli in spider-fearful participants using a prior entry paradigm. Based on the study of West and colleagues (2009), we assumed that threat-relevant stimuli of snakes and phobic stimuli of spiders would be able - comparably to threatening faces – to capture attention. These

effects would be indicated by a prior entry effect in the group of non-anxious controls as well as in the spider-fearful group. However, only the phobic stimuli of spiders in the spider-fearful group were able to capture attention. We found no effect of merely threat-relevant stimuli – neither in the control nor in the spider-fearful group. In the phobic condition, we found a shift of 6.87 ms. Comparable to the results of the first three experiments, these findings show that the influence of phobic stimuli is restricted to the group of (spider-)fearful participants (i.e., no effects were found in the group of non-anxious control participants).

In sum, we applied two different experimental designs and were able to demonstrate that phobic stimuli are preferentially processed compared to neutral and threat-relevant stimuli. Note that the two different approaches complement each other excellently. In response priming, early and automatic information processing can be assessed (cf. analysis of the 2nd and 3rd deciles of the response times distribution, Section 2.3 and 4.3). In this design, participants responses are measured which are primarily assumed to be independent of awareness (cf. dissociations between masking and priming, see Vorberg et al., 2003). However, in prior entry designs, participants are asked to indicate the temporal-order of the presented stimuli. Obviously, these judgments strongly dependent on the participant's awareness of the presented stimuli. I propose that the applied experiments and methods are suitable to fill basic research gaps in the existing literature and shed light on various aspects of information processing in non-anxious and fearful individuals.

2. Experiment 1 - Rapid visuomotor processing of phobic images in spider- and snake-fearful participants

2.1. Introduction

As described in Section 1.4. "Enhanced information processing in specific phobia", evidence points for an information processing advantage of threat-relevant in the general population; but an even stronger information processing benefit of phobic stimuli in phobic individuals. But what causes that advantage? Current studies report that the attention of individuals with specific phobias is automatically and involuntarily drawn towards the phobic stimuli. That effect is known as an attentional bias (Mogg & Bradley, 2006; Rinck & Becker, 2006; for reviews, see Mathews & MacLeod, 2005; Bar-Haim et al., 2007): as a consequence of selective attention, threatening stimuli that are attended are processed faster than unattended ones.[4] Several studies indicate that the attentional bias has a time course where early attentional capture occurs within approximately the first half second of exposure (Asmundson & Stein, 1994; Bradley et al., 1999; Mogg & Bradley, 2006; Rinck & Becker, 2006; but see also Gerdes et al., 2008).

Additionally, the early attentional bias is followed by deliberate avoidance. Rinck and Becker (2006) explored that time course using an eye-tracking study. Here, the authors compared gaze durations to four picture categories (spiders, butterflies, dogs, and cats) of spider-fearful individuals with those of non-anxious control participants and found that the first fixations (within the first 500 ms) of the spider phobics were more often on the spider pictures as compared to the first fixations of the control participants. Moreover, the early attentional bias was quickly followed by an active avoidance: After two seconds, spider-fearful participants shunned the spider pictures and, altogether, spent less time looking at them than did the control participants (for further evidence of subsequent avoidance see, e.g., Wieser, Pauli, Weyers, Alpers, & Mühlberger, 2009). According to Rinck and Becker (2006), the combination of initial attentional bias and subsequent deliberate avoidance can cause a permanent

[4] Note that the attentional bias may also base on the participants' expectancy about the appearance of their phobic object/animal (Devue et al., 2011) or other characteristics of visual perception, for instance, sudden appearance of objects (cf. Cole & Kuhn, 2009, 2010)

maintenance of specific phobias by avoidance learning. Specifically, the attentional bias will enhance the probability of detecting threatening objects, resulting in increased anxiety. In turn, the subsequent avoidance will reduce anxiety, but will also prevent sufficiently long exposures to the threatening stimuli to unlearn the initial fear response. As a result, highly anxious individuals will fail to experience that the potentially dangerous object is actually harmless.

Taken together, there is strong evidence that (1) threatening stimuli are processed faster compared to emotionally neutral stimuli and (2) this accelerated information processing is accompanied by an early attentional bias. But what are the neurophysiological processes underlying accelerated processing? Currently, there are two different accounts which try to explain that phenomenon. First, a widespread assumption is that the human amygdala plays a crucial role in rapid, automatic, and non-conscious processing of threatening stimuli (also cf. Section 6.2. "Enhanced information processing and the amygdala network"). According to this theory, two cortical pathways are involved when a feared stimulus is recognized: firstly, a slow and elaborate cortical pathway, and secondly, a subcortical route – the so-called 'low road' – which projects information directly from the thalamus to the amygdala via the pulvinar (LeDoux, 1995). In the latter case, it is assumed that the thalamic input reaches the amygdala more quickly and, therefore, might allow for rapid responses on the basis of limited stimulus information. This model is supported by recent work from different research teams (e.g., Anderson & Phelps, 2001; Morris, Öhman, & Dolan, 1999), even though some researchers challenge the role of the amygdala in rapid emotional processing (for a review, see Pessoa & Adolphs, 2010).

Alternatively to the "low road" hypothesis, the involuntary attentional bias towards fear-relevant stimuli might lead to perceptual learning processes (Kourtzi & DiCarlo, 2006; for a review, see Gilbert, Sigman, & Crist, 2001), which in turn might enable faster recognition and encoding of those stimuli (cf. Zeelenberg, Wagenmakers, & Rotteveel, 2006). The perceptual learning account with respect to enhanced object recognition can easily explain why visuomotor processing of phobic stimuli is accelerated. In object recognition, elementary features (e.g., color, form) must be bound into objects; for example, eight black pins and one black oval body may be bound into

the silhouette of a spider. According to many authors, this process requires attentional resources and should therefore be time-consuming (e.g., Treisman, 1996).

Contradicting this view, VanRullen (2009) pointed out that this assumption is in conflict with the remarkable speed of object categorization responses in natural scenes. He therefore suggests the possibility of *hardwired binding* of features to which a person is frequently exposed (i.e., perceptual learning). For example, if a person is frequently exposed to spiders, this might induce enhancements in the functional properties of the cortical arrays involved in spider detection and recognition. If the person also perceives spiders as threatening, this process might be additionally strengthened by the attentional bias. Thus, perceptual learning modulates the processing hardware concerned with that stimulus class, and so the processing advantage encompasses the first feedforward sweep of visual processing (cf. Section 1.4.2 "The rapid-chase theory of response priming").

As has been repeatedly shown, the categorization of natural images by means of speeded motor responses is very rapid[5] (Kirchner & Thorpe, 2006; Thorpe, Fize, & Marlot, 1996). Note that the two accounts described above place different demands on the time-course of the visual processing during this categorization. The amygdala account requires the "low road" to (1) classify incoming stimuli according to their emotional relevance, (2) outpace the cortical object recognition route, and (3) exert modulatory control on that processing route before it finishes processing the object. In contrast, the perceptual learning account explains enhanced processing of fear-relevant images by long-term changes in the processing hierarchy. Thus, processing enhancement for fear-relevant images could conceivably be hardwired into those processing structures involved in the first sweep of information processing through that hierarchy (*feedforward sweep*; Lamme & Roelfsema, 2000; VanRullen & Thorpe, 2001). In other words, even if the categorization of natural images is already rapid, that of fear-relevant pictures should be further enhanced. A strong prediction of perceptual learning model is that any processing enhancement should be fully present in the earliest signs of visuomotor processing. Therefore, any demonstration of processing enhancements in the earliest motor output would be consistent with a perceptual-

[5] For instance, Kirchner and Thorpe (2006) demonstrated using a forced-choice saccade task that participant reliably classified images as containing an animal or not by saccades in as little as 120 ms.

learning account and would place strict time constraints on the "low road" account, possibly strict enough to challenge its physiological plausibility.

The goal of Experiment 1 was to determine whether accelerated processing of fear-relevant and phobic images is detectable at the earliest stages of observable behavior. We used a *response priming paradigm* (Klotz & Neumann, 1999; Klotz & Wolff, 1995; Vorberg et al., 2003; also cf. Schmidt, Haberkamp, Veltkamp et al., 2011), which has not been applied in research on specific phobias before (cf. Section 1.4.1. "The response priming paradigm"). While response compatibility paradigms have been used before to study processing advantages for fear-relevant material, response priming has special properties that have not yet been demonstrated for other paradigms. Firstly, many studies have confirmed that primes directly initiate the specific motor responses assigned to them, an effect clearly discernible in the time-course of lateralized readiness potentials and overt pointing movements (e.g., Leuthold & Kopp, 1998; Schmidt, 2002). Therefore, response priming effects are directly related to the visuomotor processes triggered by visual stimuli, and are sensitive to differences in visuomotor processing. Secondly, behavioral and electrophysiological evidence links response priming to visuomotor feedforward processing, because the earliest output of the motor system is controlled exclusively by the prime but is independent of all properties of the target. This was established for goal-directed pointing responses (Schmidt et al., 2006; Schmidt & Schmidt, 2009) as well as lateralized readiness potentials (Vath & Schmidt, 2007), just as expected from a simple feedforward system that processes prime and target in strict sequence.[6]

We hypothesized that spider-fearful and snake-fearful participants will show enhanced visuomotor processing of spider or snake images, respectively, compared to neutral images and responses of a non-anxious control group, and that response priming effects can be used to measure this enhancement. We expected similar results for the two types of phobia (Åhs et al., 2009; Soares & Öhman, 1993). Based on our previous research on response priming, we predicted that enhanced processing of phobic primes will lead to larger response priming effects, and that enhanced processing of phobic

[6] Note that "response priming" is the proper name of the paradigm, named so because of the ability of the prime to trigger a motor response. There is no assumption that effects are exclusively motoric, as opposed to visual, semantic, or other priming processes.

targets will lead to faster overall response times. Because the perceptual learning account predicts that processing enhancements for fear-relevant stimuli should be apparent even in the fastest motor responses, we are especially interested in the earliest deciles of the response time distribution.

The present experiment was designed as follows. Three groups of participants took part in the study; one group of spider-fearful participants with no fear of snakes, one group of snake-fearful participants with no fear of spiders, and one non-anxious control group with no fear of either spiders or snakes. The stimuli comprised four categories of natural images (spiders, snakes, mushrooms, and flowers). We decided to use natural images due to their high ecological validity. Spider pictures are *fear-relevant* to non-anxious and snake-fearful participants, but *phobic* to spider-fearful participants. Snake pictures are fear-relevant to non-anxious and spider-fearful participants, but phobic to snake-fearful participants. Mushrooms and flowers are assumed to be *neutral* for all three groups.

In each trial of the experiment, one prime and one target, chosen randomly from one of the four stimulus categories, were presented in rapid sequence, and participants performed speeded keypress responses to classify the targets into two response categories. Participants either had to discriminate spider and snake targets from mushroom and flower targets ("animal vs. non-animal" task) or spider and mushroom targets from snake and flower targets ("spider/mushroom vs. snake/flower" task; Fig. 1).

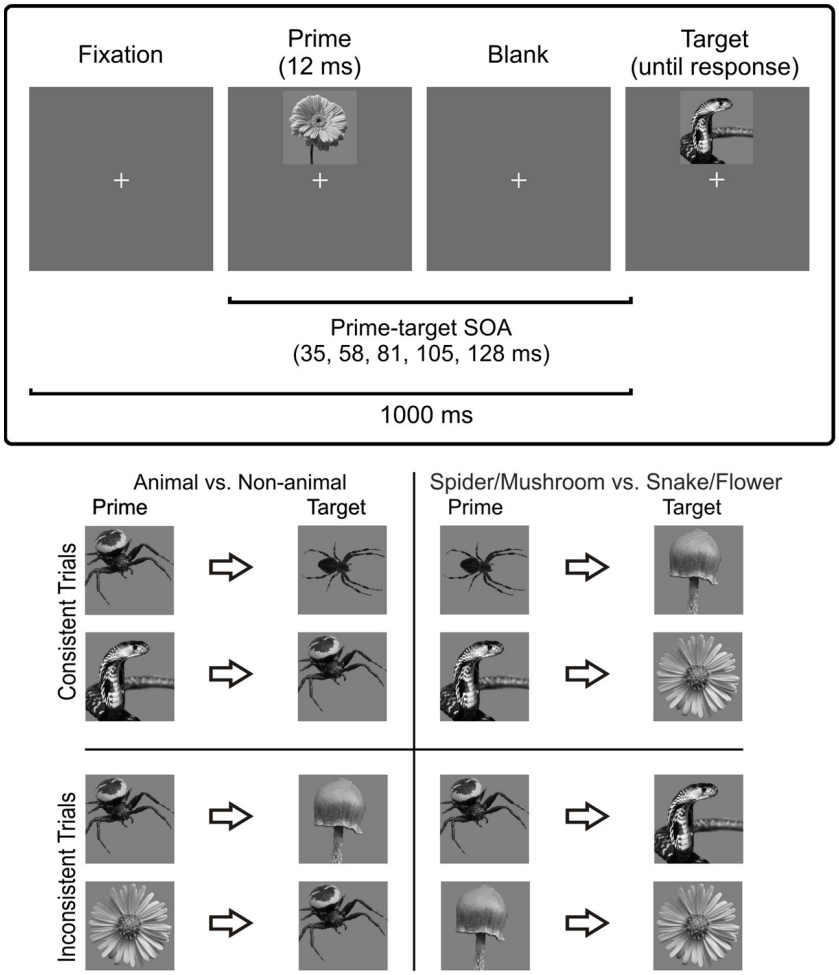

Fig. 1. Stimuli and Procedure. Upper panel: Sequence of prime and target presentation. Targets functioned as backward masks for preceding primes. In each trial, the prime was either consistent or inconsistent to the target with respect to the task-relevant motor response. Lower panel: Examples of consistent and inconsistent trials in the two tasks.

We employed a within-subjects design where the same participants were observed throughout different conditions. This design allowed us to test all our crucial predictions by comparing different types of stimuli *within any participant group*, instead of the more traditional clinical design where different groups are compared to each other. As a result, statistical precision is greatly enhanced because the total error variance between participants can be removed from the tests (Stevens, 1996). This way, data patterns can be reliably observed in single participants, especially when a small group of individuals is observed over many repeated trials. Our participants completed

six sessions with 960 trials per session, summing up to over 5,000 data points per individual. Each group had a size typical for a psychophysical response priming experiment. We consider that this approach allows us to detect small but consistent differences between stimulus conditions.

2.2. Methods

Participants. Twenty-six participants, mostly students from the University of Kaiserslautern, took part in the study. All of them were naïve to the purpose of the study. Eight of them reported that they were highly afraid of spiders but not of snakes (5 women and 3 men; age range, 20-30 years) and seven reported being highly afraid of snakes but not of spiders (5 women, 2 men; age range, 20-30 years). The remaining eight participants reported being afraid of neither spiders nor snakes (5 women, 3 men; age range, 17-24 years). All participants were screened for fear of spiders or snakes before the experiment started (Fig. 2). For this purpose, two spider questionnaires and one snake questionnaire were applied (German version of the "Spider Questionnaire" SPQ; Hamm, 2006; original version by Klorman et al, 1974; German questionnaire "Fragebogen zur Angst vor Spinnen" FAS; Rinck et al., 2002; German version of the "Snake Questionnaire" SNAQ; Hamm, 2006; original version by Klorman et al., 1974).

To ensure that the fear was specific to spiders or snakes, spider-fearful participants had to score above 75th percentile in the spider questionnaire and below 25th percentile in the snake questionnaire (and vice versa for snake-fearful participants). One participant fearful of spiders scored in the 33rd percentile of the fear-irrelevant snake questionnaire (SNAQ) but was included because of scores above 90th percentile in the SPQ. Two additional participants who reported being highly afraid of spiders were excluded after the diagnostic session due to high scores in the snake questionnaire. One additional participant who reported being highly afraid of snakes was excluded due to high scores in the spider questionnaires. These participants are already excluded from the number of participants mentioned above.

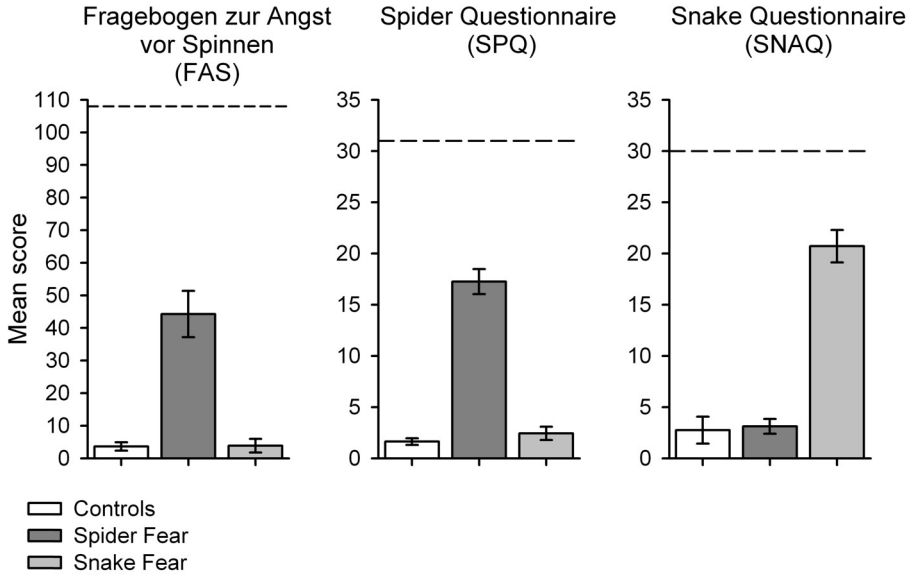

Fig. 2. Results of two spider and one snake questionnaire (German version of the "Spider Questionnaire" SPQ; Hamm, 2006; German questionnaire "Fragebogen zur Angst vor Spinnen" FAS; Rinck et al., 2002; German version of the "Snake Questionnaire" SNAQ; Hamm, 2006) separately for three different groups (non-anxious controls, spider-fearful, and snake-fearful participants). Dashed lines indicate the maximum score obtainable in the respective questionnaire.

In addition, all spider- and snake-fearful participants completed the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) and were tested for specific anxiety disorders using a structured diagnostic interview ("Diagnostic Interview for Psychological Symptoms (DIPS)"; Schneider & Margraf, 2006), based on the DSM-IV-TR (APA, 2000). According to Wittchen, Kessler, Pfister, Höfler, and Lieb (2000), a primary anxiety disorder is often followed by a secondary co-morbid depression which increases substantially with time. In contrast to phobics, depressed patients do not show an attentional bias towards negative stimuli (Eizenman et al., 2003; Mogg & Bradley, 2005) and depression slows motor responses (McDermott & Ebmeier, 2009; White, Myerson, & Hale, 1997). Since speeded responses are crucial for response priming studies, it is advisable to exclude participants with a co-morbid depression. However, none of the participants were excluded for high depression scores on the BDI (mean = 6.67, sd = 5.98).

All participants except one met at least four criteria for specific phobia (cf. Section 1.1). 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 participants in the experimental groups as "fearful" instead of "phobic".

Participants had normal or corrected-to-normal visual acuity and received payment of € 8 per hour. All of them gave informed consent and were treated in accordance with the ethical guidelines of the American Psychological Association.

Apparatus. The participants were seated in a dimly lit room in front of a color cathode-ray monitor (1280x1024 pixels, retrace rate 85 Hz) at a viewing distance of approximately 70 cm.

Stimuli and procedure. Four different categories of grayscale images (spiders, snakes, mushrooms, and flowers), each containing thirty-five different pictures (4.16° of visual angle; 1 mm ≈ 0.008° of visual angle), were presented against a lighter gray background (8.75 cd/m^2). Each trial started with the appearance of the central fixation point (cf. Fig. 1, upper panel). After a varying delay, the prime was displayed for 12 ms either above or below the fixation point at 3.74°. Subsequently, the target was presented at the same position at prime-target SOAs of 35, 58, 81, 105, or 128 ms and remained on screen until the participant's response. In each trial, the prime was either consistent or inconsistent with the target with respect to the required motor response. Prime and target pictures were pseudo-randomly drawn from one of the four different categories and a data base of thirty-five pictures for each category. All stimulus combinations of prime and target picture categories and prime-target SOA occurred equiprobably and pseudo-randomly in a repeated-measures design.

We employed two speeded target categorization tasks: All participants either discriminated spiders and snakes from flowers and mushrooms *("animal vs. non-animal" task)* or spiders and mushrooms from snakes and flowers *("spider/mushroom vs. snake/flower" task;* cf. Fig. 1, lower panel). In the "animal vs. non-animal" task, participants categorized the targets as quickly as possible by pressing the left button for snakes and spiders and the right button for flowers and mushrooms (or vice versa). In the "spider/mushroom vs. snake/flower" task, participants pressed the left button for spiders and mushrooms and the right button for snakes and flowers (or vice versa). This

contrast is essential to separate real processing advantages for phobic material from mere response biases. For instance, in the “animal vs. non-animal” task, a generalization effect from spider to snake pictures might emerge because the two unpleasant image categories are mapped to the same response. The “spider/mushroom vs. snake/flower” task controls for that effect. Note that we grouped spider with mushroom pictures because of the visual similarity of flowers and spiders, to limit effects of simple shape priming. In any task, primes and targets were classified as “consistent” when mapped to the same response, and “inconsistent” when mapped to opposite responses.

Each participant performed both tasks in separate sessions; the assignment of left and right response keys was counterbalanced across participants. Participants received immediate auditory feedback on correctness of their response after each trial. Each participant performed three 1-hour sessions performing the “animal vs. non-animal” task and three 1-hour sessions performing the “spider/mushroom vs. snake/flower” task, with order counterbalanced across participants. Each session started with one practice block followed by 29 blocks of 32 trials. Participants were debriefed after the final session and received an explanation of the experiment.

At the end of the final session, participants were asked to evaluate the images applied in the study. The rating involved three dimensions (valence, arousal, and disgust). All dimensions were rated on a six-point rating scale. Scales were coded so that high scores reflected high arousal and disgust, respectively. Positive scores in the valence ratings represent positive emotions towards the image, a score of zero means that neither positive nor negative emotions are involved, and negative scores reflect negative emotions (for results see Table 1). All three scores were submitted as dependent variables to multivariate analysis of variance with factors of group and image category. In the image rating, the groups (non-anxious controls, participants afraid of spiders, participants afraid of snakes) differed significantly regarding their evaluations. As expected, a main effect of group (Wilk's $\Lambda = 0.60$, $F(6, 156) = 7.46$, $p < .001$) and picture category ($\Lambda = 0.18$, $F(9, 189.98) = 21.73$, $p < .001$), as well as an interaction effect of group and picture category was found ($\Lambda = 0.21$, $F(18, 221.10) = 9.15$, $p < .001$), reflecting the fact that fearful participants rated their phobic images more negatively on all three dimensions as compared to neutral images or non-fearful participants. Note that the group of spider- and snake-fearful participants rated the

picture categories of their specific fear comparably over all three dimensions (Spider fear: Arousal: 3.12, Disgust: 4.26, Valence: -2.55; Snake fear: Arousal: 3.45, Disgust: 4.31, Valence: -2.30). Therefore, we conclude that the phobic images induce similar amounts of discomfort in spider- and snake-fearful participants.

Table 1: Participants' mean scores (with standard deviations) for image evaluation separately for scale (valence, arousal, and disgust) for each picture category and each group. Bold letters indicate phobic image categories.

	Arousal				Disgust				Valence			
	Spider	Snake	Mushroom	Flower	Spider	Snake	Mushroom	Flower	Spider	Snake	Mushroom	Flower
Controls	0.61 (0.86)	0.67 (1.00)	0.39 (0.65)	0.58 (0.89)	0.98 (1.17)	0.23 (0.61)	0.43 (0.73)	0.04 (0.19)	-0.40 (1.07)	0.00 (0.92)	-0.27 (1.01)	0.35 (1.02)
Spider Fear	**3.12 (1.31)**	0.66 (0.92)	0.17 (0.47)	0.06 (0.23)	**4.26 (1.38)**	0.69 (0.92)	0.34 (0.90)	0.01 (0.10)	**-2.55 (0.74)**	-0.15 (0.87)	-0.15 (0.53)	1.04 (0.94)
Snake Fear	1.01 (1.11)	**3.45 (1.46)**	0.11 (.034)	0.10 (0.38)	1.01 (1.11)	**4.31 (1.43)**	0.16 (0.57)	0.01 (0.11)	-0.61 (0.84)	**-2.30 (0.71)**	-0.07 (1.00)	1.18 (1.32)

Data treatment and statistical methods. Practice blocks were not analyzed. Trials were eliminated if response times were shorter than 100 ms or longer than 1000 ms, and if, incidentally, prime and target consisted of the exact same image. These criteria eliminated 1.51 % of trials in the "animal vs. non-animal" task and 1.79 % of trials in the "spider/mushroom vs. snake/flower" task. Repeated-measures analyzes of variance (ANOVAs) were performed with Greenhouse-Geisser-corrected p values. We report F values with subscripts indicating the respective effect (e.g., F_{CxS} for the

interaction of consistency and SOA). Additionally, we report the effect size η^2 (cf. Levine & Hullett, 2002).[7]

2.3. Results

The large number of conditions in this experiment requires a principled way of analyzing the data. We organized the results section according to a robust empirical principle in response priming, namely, that the strength of the target stimulus mainly affects total response times, while the strength of the prime mainly affects the size of the priming effect. The results section will be structured as follows. Within each of the three groups (controls, spider-fearful, snake-fearful), we will first analyze the *influence of the targets on overall response times* as a measure of response activation by the different targets (spider, snakes, mushrooms, flowers). Second, we will examine the *influence of the primes on response priming effects* as a measure of response activation by the primes. Finally, we will show that the effects found in the general response times are already present in the fastest responses (r*esults of 2nd and 3rd deciles*). (The 1st percentile is not well suited for such an analysis because it is too dependent on the exact outlier criteria.)

2.3.1. Influence of the targets on overall response times

In this analysis, we look at overall response time (averaged across consistent and inconsistent primes) as a measure of response activation by the target. Because we found no significant interactions of the task factor with any of the other factors, we averaged the response times for both tasks (Fig. 3, upper plot). We performed an analysis of variance (ANOVA) with factors of group *(G*; controls, spider-fearful, snake-fearful*)*, target category (*T;* spider, snake, mushroom, flower), prime-target consistency (*C;* consistent, inconsistent), and SOA (*S;* 35, 58, 81, 105, 128 ms). However, because consistency and SOA effects are not of theoretical interest in this particular analysis, I do not report them here. The test on the interaction of group and target was significant,

[7] Note that according to Cohen (1988) an effect size (η^2) of 0.01 reflect a small, of 0.059 a medium, and of 0.138 a large effect.

$F_{GxT}(6, 60) = 5.45$, $p = .001$, $\eta^2 = 0.179$, confirming our prediction that target effects differed systematically between groups.

Additionally, we performed an ANOVA for each group. We had predicted that participants fearful of spiders or snakes should respond faster to their respective phobic targets than to any other target category, while no such processing preference should occur in the non-anxious control group. Indeed, in the control group, participants responded equally fast to all types of targets ($F_T(3, 21) = .87$, $p = .428$, $\eta^2 = 0.010$; Fig. 3). In spider-fearful individuals, however, target category strongly influenced response times, mainly because responses were much faster when the target was a spider ($F_T(3, 21) = 12.71$, $p = .005$, $\eta^2 = 0.195$). Planned paired comparisons between the phobic targets and the remaining target categories confirmed significant differences for each contrast (*"spider/mushroom vs. snake/flower" task:* $F_T(1, 7) = 16.47$, $p = .005$; *spider vs. mushroom:* $F_T(1, 7) = 20.21$, $p = .015$; *spider vs. flower:* $F_T(1, 7) = 14.52$, $p = .007$). In fact, response times to spider targets were about 43 ms faster compared to other targets. For participants fearful of snakes, responses to snake targets also were numerically faster, but not significantly so ($F_T(3, 18) = 2.95$, $p = .115$, $\eta^2 = 0.091$). Also, paired comparisons did not reveal significant differences between target types (snake vs. spider: $F_T(1, 6) = 0.62$, $p = .460$; snake vs. mushroom: $F_T(1, 6) = 4.17$, $p = .087$; snake vs. flower: $F_T(1, 6) = 5.87$, $p = .052$). Note, however, that the differences between snake targets and flower and mushroom targets approached significance.

Faster responses to phobic targets did not result from a speed-accuracy trade-off, as shown in Figure 3 (lower panel). In particular, spider-fearful participants responded not only faster but also more accurately when the target was a spider, and responses to phobic targets were also more resistant to priming effects.

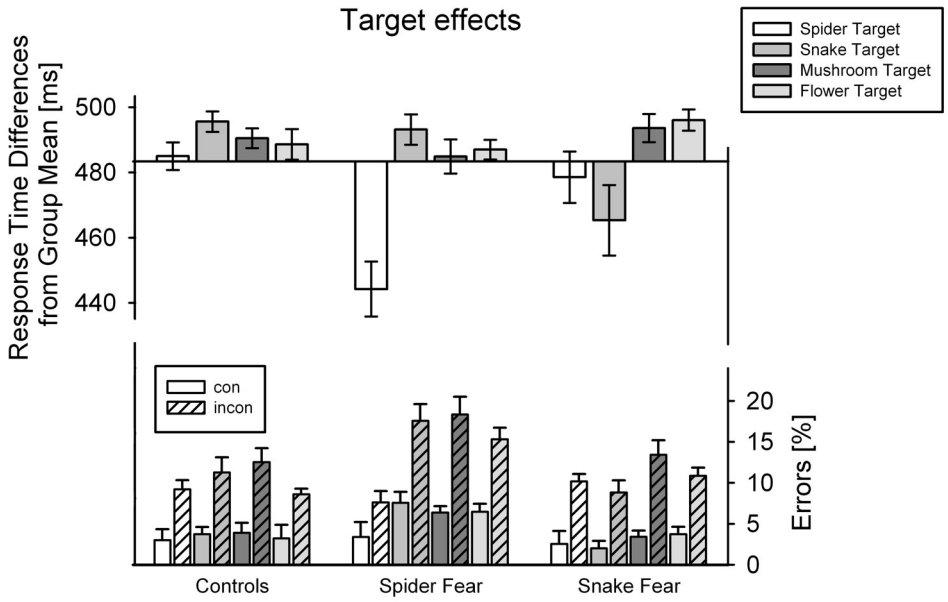

Fig. 3. Upper panel: Response times to different target types averaged over both tasks for each group, shown relative to the grand average response time. Lower panel: Error rates (in percentage) are displayed separately for consistent trials (plain bars) and inconsistent trials (patterned bars). In both plots, different gray scales indicate different target types. Here and in all remaining figures, error bars denote standard errors of the mean with pure intersubject variance removed (Cousineau, 2005).

2.3.2. Influence of the primes on priming effects

In this analysis, we looked at response priming effects (defined as response time differences between consistent and inconsistent trials) as a measure of response activation by the primes. For each group, we performed an ANOVA with factors of prime (*P*; spider, snake, mushroom, flower), consistency *(C),* and SOA *(S)*. We predicted that participants fearful of spiders or snakes should show larger priming effects by their respective phobic primes than by any other prime category, while no such processing preference should occur in the non-anxious control group.

Response times for the different groups and prime types in the two tasks are displayed in Figure 4. Averaged across prime type, consistent trials (where prime and target stimuli belonged to the same response category) produced faster response times than inconsistent trials for each group and task ("animal vs. non-animal",

"spider/mushroom vs. snake/flower", respectively; *controls*: $F_C(1, 7) = 63.26$, and 95.00, both $p < .001$, $\eta^2 = 0.222$ and $\eta^2 = 0.366$; *spider fear*: $F_C(1, 7) = 163.96$, and 189.96, both $p < .001$, $\eta^2 = 0.268$ and $\eta^2 = 0.204$; *snake fear*: $F_C(1, 6) = 92.95$, and 74.02, both $p < .001$, $\eta^2 = 0.284$ and $\eta^2 = 0.224$). Also, priming effects increased with prime-target SOA for all groups and tasks (*controls*: $F_{CxS}(4, 28) = 12.02$, and 13.65, $p = .001$ and $p < .001$, $\eta^2 = 0.016$ and $\eta^2 = 0.038$; *spider fear*: $F_{CxS}(4, 28) = 25.13$, and 17.67, both $p < .001$, $\eta^2 = 0.032$ and $\eta^2 = 0.022$; *snake fear*: $F_{CxS}(4, 24) = 20.35$, and 18.06, both $p < .001$, $\eta^2 = 0.025$ and $\eta^2 = 0.030$).

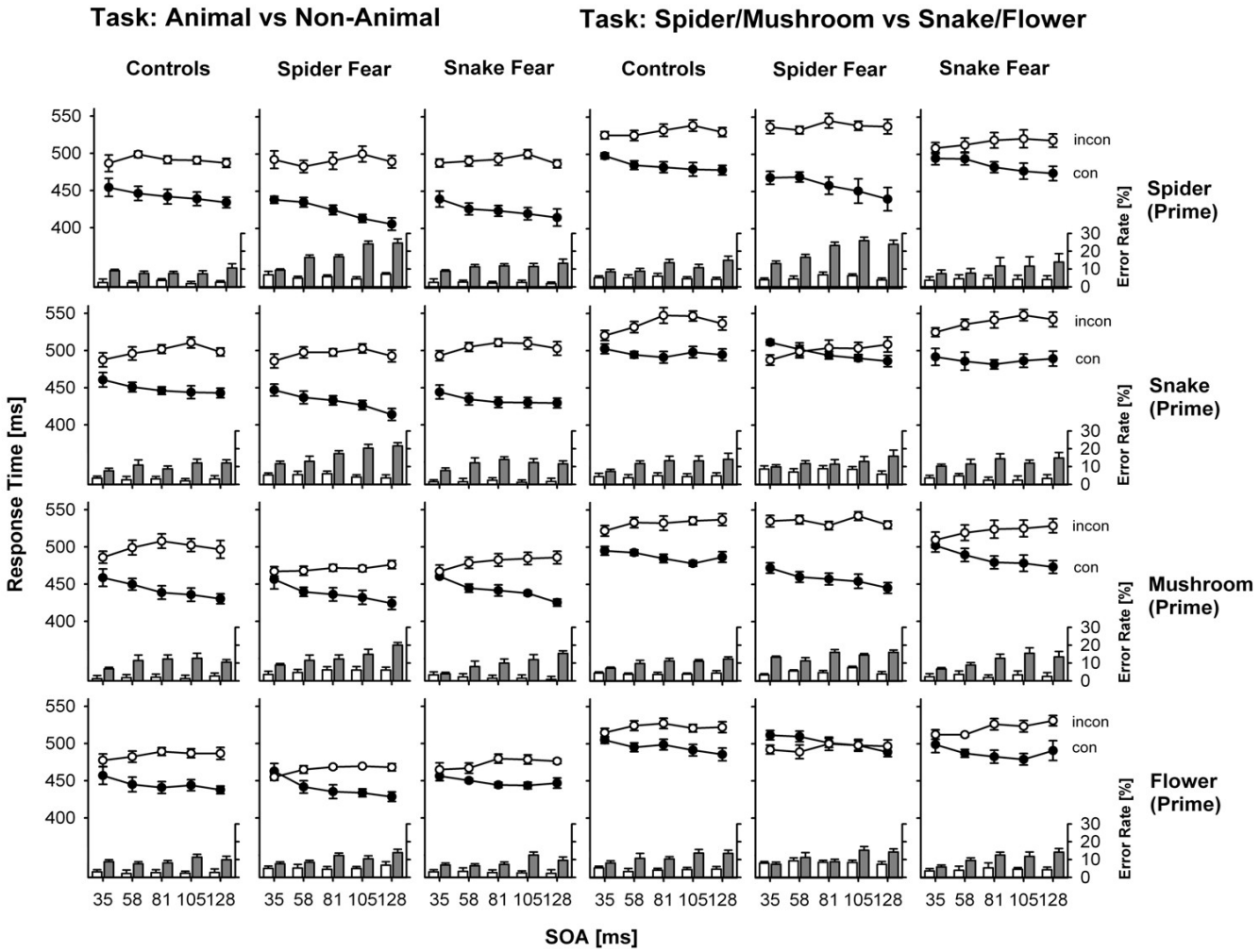

Fig. 4. Response times and error rates in each task and group, separately for different prime types.

Response priming effects can be observed in error rates as well as response times. Because consistent primes activate only correct responses whereas inconsistent primes activate only incorrect responses, errors should be observed predominantly in inconsistent trials at long SOAs where the primes have had a lot of time to drive the incorrect response (Vorberg et al., 2003). Figure 4 shows that priming effects in error rates closely follow those in the response times. In particular, participants fearful of spiders show large error rates when the target is preceded by a response-inconsistent spider prime. No such effect is discernible in the snake-fearful participants, in accordance with the pattern in the response times.

In the following, we report the results separately for each task, for the four different prime types, and for each group, and highlight the differences between the control and the two experimental groups.

"*Animal vs. non-animal" task.* An ANOVA with factors of group *(G)*, prime (*P*), consistency *(C),* and SOA *(S)* yielded no significant interactions of the group factor with either prime type or priming effect ($F_{GxP}(6, 60) = 1.90$, $p = .116$, $\eta^2 = 0.079$; $F_{GxPxC}(6, 60) = 1.72$, $p = .196$, $\eta^2 = 0.102$).

"*Spider/mushroom vs. snake/flower" task.* In the previous task, spider and snake stimuli were always mapped to the same motor response. If participants developed a bias against the response assigned to the phobic stimuli (e.g., the spiders), this bias would translate to the other animal category as well (i.e., the snakes), and differences between phobic and merely fear-relevant stimuli could not be interpreted. The "spider/mushroom vs. snake/flower" task allows us to compare phobic and merely fear-relevant primes in a situation where they are mapped to different responses. We predict faster overall response times to phobic targets as compared to other target categories, larger priming effects by phobic primes as compared to other prime categories, and no such effects of stimulus type in the control group. An ANOVA with factors of group *(G)*, prime (*P*), consistency *(C),* and SOA *(S)* revealed that response times to the four different prime types varied significantly across groups, $F_{GxP}(6, 60) = 3.90$, $p = .006$, $\eta^2 = 0.169$, and that the priming effects elicited by those prime types also differed across groups, $F_{GxPxC}(6, 60) = 5.18$, $p = .010$, $\eta^2 = 0.285$.

As expected, non-anxious control participants showed no differences in priming effects for the four different prime categories ($F_{PxC}(3, 21) = 2.56$, $p = .135$, $\eta^2 = 0.020$) or the two different prime response classes (spiders and mushrooms forming one class, snakes and flowers the other; $F_{PxC}(1, 7) = 2.05$, $p = .195$, $\eta^2 = 0.012$). In contrast, in spider-fearful participants priming effects differed significantly for the four different prime categories ($F_{PxC}(3, 21) = 11.64$, $p = .007$, $\eta^2 = 0.194$) as well as for the two different prime response classes ($F_{PxC}(1, 7) = 13.42$, $p = .008$, $\eta^2 = 0.196$). However, no significant differences in priming effects were found for participants specifically fearful of snakes (four primes: $F_{PxC}(3, 18) = .34$, $p = .599$, $\eta^2 = 0.010$; two prime response classes: $F_{PxC}(1, 6) = 1.04$, $p = .347$, $\eta^2 = 0.002$).

For further understanding of that pattern, we separated response times in the two groups by both prime and target category (Fig. 5). This analysis reveals that priming effects are difficult to evaluate without taking the main effects of target type into account. Specifically, responses to phobic targets (spiders for spider-fearful, snakes for snake-fearful participants) were relatively faster than those to neutral targets (mushrooms or flowers). For instance, when spider-fearful participants responded to phobic spider targets, their responses were fast even if these targets followed an inconsistent prime. As a result, priming effects are *augmented* when a phobic target is response-consistent with the prime, because then the response to the consistent target is speeded both by the priming effect and by the main effect of target type. Similarly, priming effects are *reduced* or even appear to vanish when a phobic target appears in the response-inconsistent role, because then the response is slowed by the priming effect but still speeded by the main effect of the target. This augmentation-reduction pattern is especially pronounced in the spider-fearful group when responding to spider targets; it is less apparent for the snake-fearful group when responding to snake targets (cf. Fig. 4). This is of course a consequence of the larger target main effects in the spider-fearful group.

In sum, the response pattern in the "spider/mushroom vs. snake/flower" task is similar to the "animal vs. non-animal" task, indicating that any differences between phobic and merely fear-relevant images cannot be attributed to the fact that they are

both assigned to the same response category. However, it is noteworthy that participants responded up to 43 ms slower in the "spider/mushroom vs. snake/flower" than in the "animal vs. non-animal" task. This might be due to higher demands in the former task. Specifically, in the "animal vs. non-animal" task, the response categories are consistent with an intuitive, natural categorization of the environment, whereas in the "spider/mushroom vs. snake/flower" task, participants had to learn a purely arbitrary assignment.

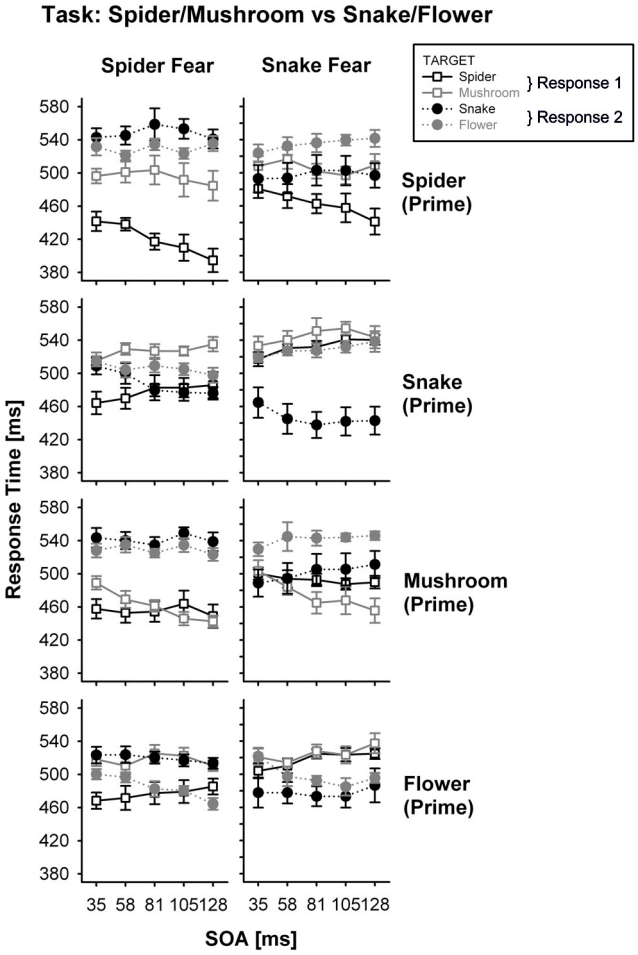

Fig. 5. Response times of spider and snake fearful individuals in the "spider/mushroom vs. snake/flower" task, separately for different prime and target types.

2.3.3. Results of 2nd and 3rd deciles

If the processing advantage for fear-relevant material is due to long-term perceptual learning processes, the advantage could already affect the first sweep of processing running through the visuomotor system. If so, processing advantages should be fully present in the fastest responses (Schmidt, Haberkamp, Veltkamp et al., 2011). This is true for the effect of phobic targets on overall response times (Fig. 6; cf. Fig. 3) as well as for the effect of phobic primes on the magnitude of priming effects (Fig. 7). There is no indication in our data that these effects become any larger with increasing response time.

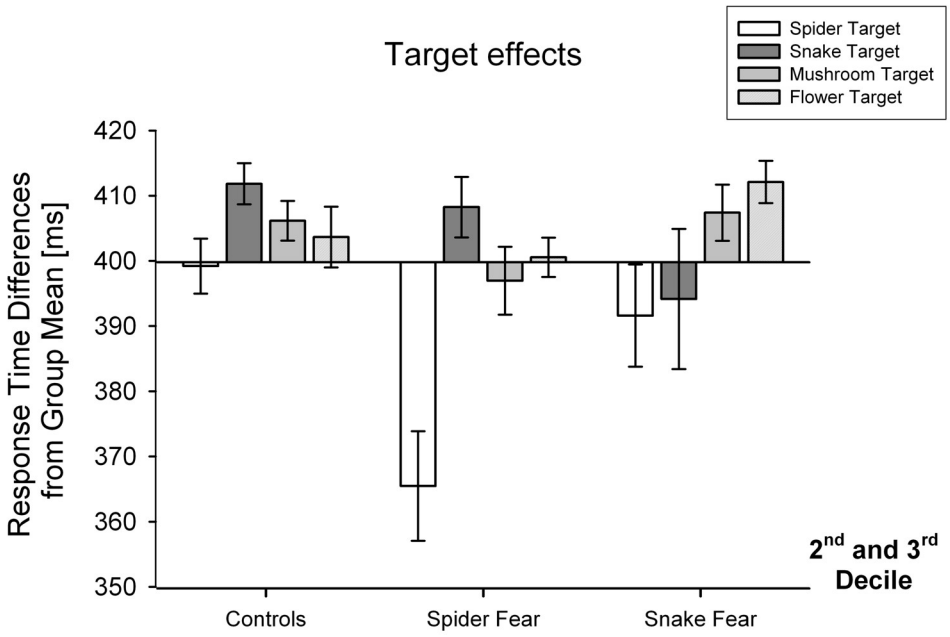

Fig. 6. Response times to different targets averaged over both tasks for each group, shown relative to the grand average response time for 2nd and 3rd deciles of the response time distribution.

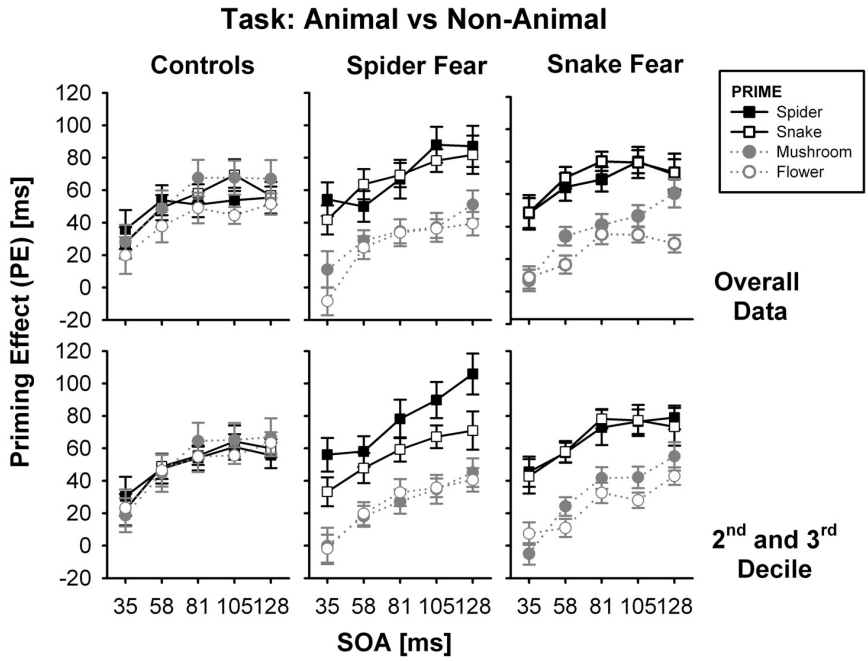

Fig. 7. Priming effects (PE) in overall response times (upper row) compared to PEs in the 2nd and 3rd deciles (lower row) for the "animal vs. non-animal" task.

2.4. Discussion

Overall, we found robust response priming effects in all groups and tasks, where inconsistent primes led to slower response times compared to consistent ones, and these priming effects increased with prime-target SOA (complications to this overall data pattern are discussed below). These findings are in line with previous results from the image categorization literature (e.g., Bacon-Macé, Kirchner, Fabre-Thorpe, & Thorpe, 2007; Kirchner & Thorpe, 2006) as well as response priming studies with natural images (Schmidt & Schmidt, 2009), showing that natural images are able to rapidly activate the motor responses assigned to them.

The purpose of the present study was to utilize such response priming effects to demonstrate enhanced visuomotor processing of phobic stimuli relative to merely fear-relevant and neutral stimuli, and to investigate whether such processing advantages might conceivably be due to enhanced feedforward processing of visual stimuli. Of special interest are systematic differences in the processing of different image categories within each group of spider-fearful, snake-fearful, and non-anxious control participants.

In response priming studies, such differences should show up in the overall response times (reflecting processing aspects of the target) as well as in the magnitude of priming effects (reflecting processing aspects of the prime).

In the non-anxious control participants, we found no systematic differences in their responses towards the different target categories (spiders, snakes, mushrooms, or flowers), neither in the "animal vs. non-animal" nor in the "spider/mushroom vs. snake/flower" task. Also, all primes produced strong and reliable priming effects whose magnitudes did not differ for the different prime categories. We had been prepared to find processing advantages for fear-relevant images in accordance with recent findings (e.g., Anderson & Phelps, 2001; Öhman, Flykt et al., 2001; Piech et al., 2010), at least in the "animal vs. non-animal" task. In that task, the simple categorization of animal vs. non-animal targets is known to lead to fast categorization responses, so that mapping spider and snake images to the same response might reveal a processing difference between fear-relevant and neutral stimuli even in control participants. The absence of such differences in our results is consistent with the fact that control participants rated the images of spiders and snakes as only slightly negative, arousing, or disgusting (Table 1). Similarly, Tipples and colleagues (2002) did not find any biases for threatening stimuli in non-anxious individuals in a visual search task. The conflicting findings suggest that non-anxious control participants in various studies may differ in research-relevant characteristics, such as their trait/state anxiety (see, e.g., Koster, Verschuere, Crombez, & Van Damme, 2005; Mogg, Bradley, Miles & Dixon, 2004).

Importantly, spider-fearful participants showed a strongly different result pattern. Firstly, they responded more rapidly to spider targets as compared to snake, mushroom, and flower targets. Secondly, their responses to spider targets were exceptionally fast even in cases where these targets followed an inconsistent prime. The fast responses to spider targets strongly affected the size of the priming effect. This can most clearly be seen in the "spider/mushroom vs. snake/flower" task. For instance, if the prime was a spider, a subsequent spider target led to exceptionally large priming effects because fast responses to the spider target became even faster by consistent priming. In contrast, when the prime was a snake, priming effects were reduced because responses to the spider target were still relatively fast, even though the target was inconsistent to the prime. As a result, priming effects are augmented if spider targets appear in

consistent conditions and are diminished if they appear in inconsistent conditions. Taking this complication into account, our results clearly show that spider targets and spider primes lead to faster responses and larger priming effects, respectively, in participants fearful of spiders, compared to other image categories. One could argue that the observed differences in the spider-fearful group are due to differences in low level vision. However, as one reviewer pointed out the results of the non-anxious control group demonstrate comparable processing efficiency for all different image types.

Unexpectedly, snake-fearful participants showed a response pattern different from that in the spider-fearful group. In comparison to responses to neutral images, they tended to respond somewhat faster not only to snake targets, but also to spider targets. However, neither effect was significant, so it has to be concluded that information processing was not specifically accelerated by snake pictures. In the "animal vs. non-animal" task, priming effects were significantly larger when an animal prime was shown compared to trials when non-animal primes were presented, but again, there were no discernible differences between snake and spider primes. Furthermore, even though response times to animal targets were faster than those to non-animal targets, the faster responses occurred indiscriminately within the category of animal pictures, that is, snake-fearful participants did not respond specifically faster to their phobic picture category. Thus, it seems that they show enhanced information processing not limited to snake pictures, but to fear-relevant animal stimuli in general. However, some care is needed when interpreting these group differences, since this is an accidental finding not previously reported in the literature and our experiment is designed to pick up differences between stimuli within groups rather than differences between groups.

The major reason for applying two tasks with different stimulus-response mappings was to control for generalization effects, that is, effects in response times to snake targets emerging solely because spiders and snakes are matched to the same motor response. The "spider/mushroom vs. snake/flower" task controls for such effects. In the present results, however, response time effects in all groups can be traced back to the specific image category presented as prime or target. In other words, no generalization effects are apparent in the present study, so that both tasks seem suited for measuring enhancements in response activation. The comparison of the two tasks also tells us something about the type of information on which the response priming

effect is based. In the "animal vs. non-animal" task, several types of information may conspire to prime a response: the semantic information about the animacy of primes and targets, the affective information about the pleasantness of fear-relevant vs. neutral image categories, and the stimulus-response mapping assigned at the outset of the experiment. In contrast, the "spider/mushroom vs. snake/flower" task makes stimulus-response assignments orthogonal to the animacy and pleasantness distinctions, leaving only the visuomotor mapping as a source of priming information. As similar priming effects and processing enhancements are observed in both tasks, we can exclude semantic as well as affective information as *exclusive* sources of priming. Otherwise, neutral pictures of mushrooms and flowers would not have been able to prime fear-relevant pictures of spiders and primes (and vice versa), which is what we found in the "spider/mushroom vs. snake/flower" task (Fig. 5). On that note, we also can preclude pure identity priming because responses are always activated by both types of stimuli that are assigned to it.

2.4.1. Underlying mechanisms of rapid information processing

As described in the introduction, two different accounts attempt to explain enhanced information processing by threatening stimuli: acceleration due to increased *amygdala activation* and *long-term perceptual learning* mechanisms. The perceptual learning account with respect to enhanced object recognition can easily explain why enhanced processing of phobic stimuli is evident in the fastest responses of the response time distribution (cf. Section 2.1). Indeed, in the present data all modulatory effects of phobic material on response times and priming effects were fully present in the fastest responses, that is, in the 2nd and 3rd deciles of the response time distribution, consistent with such a simple feedforward model.

Note that the perceptual learning account could also accommodate differential enhancement for different phobias. For instance, because the likelihood of encountering a snake is low for German participants compared to the likelihood of encountering a spider, our snake-fearful participants may have had less opportunity for perceptual learning than the spider-fearful participants, and less incentive for continued vigilance in interactions with their everyday environment. However, since our study was not

designed to investigate group rather than stimulus differences, this suggestion is somewhat speculative at this point.[8]

Our finding that the processing advantage of phobic stimuli already affects the fastest responses places serious time constraints on any explanation involving the amygdala, especially considering the processing speed of the structures involved (cf. Piech et al., 2010; Tsuchiya et al, 2009). If images can indeed be classified during the first feedforward sweep of visuomotor processing (Schmidt & Schmidt, 2009; Thorpe et al., 1996; VanRullen & Thorpe, 2001), the amygdala pathway would be required to (1) classify incoming stimuli as emotionally relevant, (2) outpace the cortical object recognition route, and (3) exert modulatory control on that processing route before it finishes processing the object. It is questionable whether all these processes can take place in the minimal time available in the rapid categorization task that we used, considering that all amygdala modulation of the object-recognition pathway must be finished before the fastest responses are completed. Mormann and colleagues (2011) analyzed response latencies from single neurons in the amygdala and found that they responded to animal pictures within 324 ms, significantly faster than to other image categories. The authors argue that this enhancement may reflect the biological importance of animal pictures, but stress that "the observed amygdala latencies are nevertheless similar to those found in other regions in the temporal lobe, and thus seem more likely to be generated along the cortical object recognition pathway than via a rapid subcortical route" (p. 1248).

Note that the amygdala's response time reported by Mormann and colleagues (2011) is already close to the fastest keypress responses to spider targets in our study, which average about 365 ms in the 2nd and 3rd deciles of the response time distribution. Moreover, the time when the keypress response is completed is preceded by a phase of motor preparation that takes about 100 ms and can be traced, for instance, in lateralized readiness potentials (cf. Vath & Schmidt, 2007). Thus, when these timing issues are

[8] Note, however, the interesting prediction that individuals fearful of spiders *as well as* snakes should show a response pattern similar to those of the spider-fearful participants and, at the same time, should show no enhanced processing of snake pictures. This is exactly what we found in the three participants who were excluded from the main analyses because they scored high in both the spider and snake questionnaires. However, these findings have to be interpreted with caution due to the very small sample size.

considered together, the amygdala seems just too slow to modulate visuomotor processing of primes or targets in an on-line fashion (see also Pessoa & Adolphs, 2010). It may, however, be crucial for the emotional response experienced after or simultaneously with the ongoing motor response.

In addition, if enhanced processing were due to an *emotional* response at all, one would expect the enhancement to be predictable from the emotional evaluation of the stimulus. Spider-fearful and snake-fearful participants in our study gave comparable ratings to their phobic stimuli, respectively, yet strong processing enhancements for phobic material only occurred in spider-fearful participants, while snake-fearful participants showed only slight enhancements for both types of animal stimuli. Of course we did not measure amygdala activation directly and have to infer it from the self-reported fear levels; so we cannot rule out that amygdala activation might differ across experimental groups. But even if the processing enhancement was indeed based on a signal by the amygdala, this response would be required to occur freshly for each stimulus presentation, without much fatigue or adaptation, over the course of several thousand trials. All this suggests that emotional activation by the amygdala may not play a causal role in speeding perceptual processing on-line, that is, on a trial-to-trial basis. In the long run, however, emotional responses directed by the amygdala may play an important role in promoting long-term perceptual learning.

In summary, our results show that phobic stimuli are processed faster in the visuomotor system as compared to merely fear-relevant or neutral ones, as revealed by differences in response times and response priming effects. This processing advantage is fully present in the fastest motor responses but may occur only in spider-fearful but not snake-fearful individuals. These findings support the notion that long-term perceptual learning processes underlie the automatic and rapid information processing of threatening images, and conflicts with the idea that the amygdala is involved in the online enhancement of these processes.

3. Experiment 2 - Target- and prime-identification tasks in spider-fearful participants

3.1. Introduction

In Experiment 1 (Chapter 2), we demonstrated that spider-fearful participants exhibited specific information processing styles of phobic images. Firstly, they reacted particularly fast to spider targets and, secondly, spider primes led to larger priming effects in their motor responses compared to snake, mushroom, or flower primes (dependent on the respective task). The observed enhanced information processing of fear-relevant stimuli, reflected in faster response times, is in line with recent studies (e.g., Fox et al., 2007; Öhman, Flykt et al., 2001; Pflugshaupt et al., 2005).

This effect can be explained by the theoretical assumption that automatic information processing of threat-relevant stimuli is preconscious and inaccessible to intentional control (Öhman, Flykt et al., 2001). Öhman and Soares (1994) proposed that typical symptoms of fear arise when phobic persons are confronted with phobic stimuli even before they are aware of it. In their study, spider-, snake- and non-fearful participants were confronted with masked and unmasked target pictures of spiders, snakes, flowers, and mushrooms. In the first experiment, pictures were presented for 30 ms and the target-mask SOA was varied between 20 ms and 180 ms. The authors reported that participants were not able to indicate the picture content at target-mask SOAs of 30 ms. Accordingly, they assumed that participants were unaware of the pictures presented at that specific mask-target SOA. Therefore, they presented the images with an SOA of 30 ms in a second experiment and measured *skin conductance responses (SCRs)*.[9] They reported that subliminal as well as supraliminal (i.e., masked as well as unmasked) phobic pictures elicited increased SCRs in spider- and snake-fearful participants. Thus, the authors concluded that indeed subliminal presentation of phobic stimuli induces fear responses.

Though, the study suffered from a methodological problem. The authors tested the visibility of the pictures with different participants than those that took part in their main experiment. However, the target-mask SOAs at which visibility is at chance level

[9] Note that SCRs are used as an indication of psychological arousal. Arousal activates the sympathetic nervous system which controls the sweat glands of the skin. These moisture changes alter the electrical conductance of the skin which can be measured by SCRs (Martini & Bartholomew, 2003).

varies a great deal for different persons (cf. Marcel, 1983). In order to test that the presented pictures are really subliminal one has to identify each participant's individual threshold. Therefore, I presume that the participants in Öhman and Soares' (1994) study were not completely unaware of the presented picture category. Indeed, Mayer, Merckelbach, de Jong, and Leeuw (1999) replicated Öhman and Soares' (1994) study and observed that their participants were able to correctly identify most of the presented pictures in a four-alternative forced choice paradigm. Hits (e.g., number of spider pictures identified as spiders) frequently exceeded the chance probability (25 percent).

However, evidence exists that spider-fearful individuals indeed process threat-relevant stimuli faster compared to other stimuli, and that this may happen even when the participants are not aware of them (cf. Siegler, Anderson, & Han, 2011; Straube, Mentzel, & Miltner, 2006). In Experiment 1 (Chapter 2), we provided evidence that this processing bias might be based on long-term perceptual learning processes. In terms of neural plasticity, it can be assumed that due perceptual learning processing neurons should respond specifically well towards spiders in spider-fearful individuals (cf. Section 6.3.2. "The neural basis of perceptual learning"). From this, we derived the hypothesis that perceptual learning may also lead to better identification performance of spider-fearful participants when confronted with masked spider pictures. In particular, these participants should be able to detect spiders, even when they are masked and presented at short picture-mask SOAs.

The design of the present study is almost identical to that of Experiment 1 (Chapter 2) except for three small but important changes. Firstly, we reduced the number of SOA levels from 5 to 2 to reduce the number of conditions, using a short SOA of 35 ms – a situation of strong masking where we assumed that the prime would be almost invisible – as well as a long SOA of 105 ms – a situation of weak masking where we assumed that the prime could be easily identified. Secondly, we changed the spatial configuration of the stimuli to be able to present a backward *pink-noise* (or *1/f noise*) mask on the position of the prime (simultaneously with the identical target pictures on the left and on the right). That means that the prime was presented for 24 ms above (or below) the fixation cross, and then the two target pictures appeared (Fig. 8). Thirdly, we introduced a *Prime Identification* task. In that task, participants were asked to identify and categorize the briefly presented primes.

Our results from Experiment 1 (Chapter 2) and the literature review on recent studies on threat-relevant masked stimuli led us to the following hypotheses. (1) We expected that the results in the target identification task would replicate those of the same task in Experiment 1: spider-fearful participants should respond specifically faster to spider targets and should show larger priming effects if the target is preceded by a spider prime. (2) We expected that spider-fearful participants would outperform non-anxious control participants in the identification of masked and unmasked spider primes due to preceding perceptual learning processes.

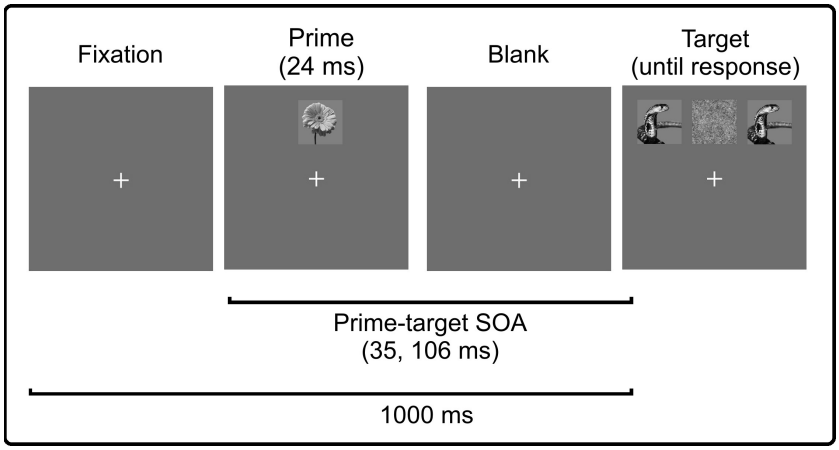

Fig. 8. Stimuli and Procedure. Primes and targets were presented in the sequence displayed. Primes and targets were either consistent or inconsistent with respect to the required motor response. In half of the sessions, the target pictures were accompanied by a pink-noise mask at the position of the prime.

3.2. Methods

Participants. Sixteen participants, mostly students from the University of Kaiserslautern, took part in the study. Eight of them reported to be highly afraid of spiders (5 women and 3 men; age range, 20-23 years) and eight reported not to be afraid of spiders (6 women and 2 men; age range, 21-24 years). All participants were screened for fear of spiders before the experiment started. We applied two spider questionnaires

and one snake questionnaire[10] (German version of the "Spider Questionnaire" SPQ; Hamm, 2006; original version by Klorman et al., 1974; German questionnaire "Fragebogen zur Angst vor Spinnen" FAS; Rinck et al., 2002; German version of the "Snake Questionnaire" SNAQ; Hamm, 2006; original version by Klorman et al., 1974). The results are depicted in Figure 9. Control participants scored in the SPQ on percentile 25 or below relative to a normative sample. In the group of spider-fearful participants, men scored at least on percentile 80, and women at least on percentile 85. For the FAS only guideline values are available. According to these values, spider-fearful participants should at least score above 14 (Rinck et al., 2002).

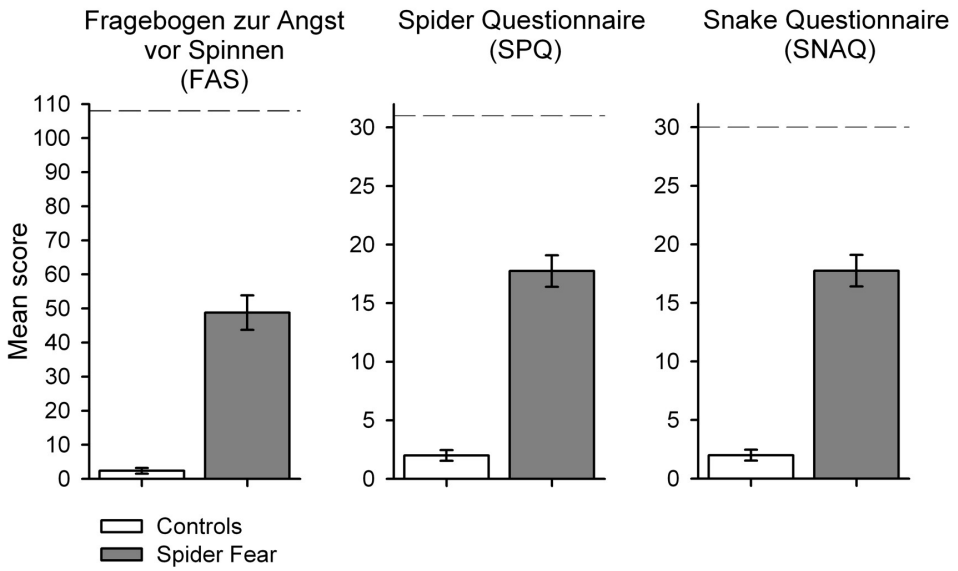

Fig. 9. Results of two spider and one snake questionnaire (German version of the "Spider Questionnaire" SPQ; Hamm, 2006; German questionnaire "Fragebogen zur Angst vor Spinnen" FAS; Rinck et al., 2002; German version of the "Snake Questionnaire" SNAQ; Hamm, 2006) separately for three different groups (non-anxious controls, spider-fearful, and snake-fearful participants). Dashed lines indicate the maximum score obtainable in the respective questionnaire.

In addition, spider-fearful participants were tested for specific phobias using a structured diagnostic interview ("Diagnostic Interview for Psychological Symptoms

[10] Note that we additionally applied a snake questionnaire because we wanted to exclude spider-fearful individuals with a secondary fear of snakes.

(DIPS)"; Schneider & Margraf, 2006), based on the DSM-IV-TR (APA, 2000). All participants except one met at least four criteria out of five for specific phobia of spiders. The criterion that was unsatisfied in all 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 again refer to these participants as spider-fearful participants but not as phobics. Finally, all participants completed the Beck Depression Inventory (BDI; Beck et al., 1961). None of the participants had to be excluded for high depression scores on the BDI (mean = 6.13, sd = 5.58).

All participants had normal or corrected-to-normal visual acuity and received payment of € 6 per hour. All of them gave written informed consent and were treated in accordance with the ethical guidelines of the American Psychological Association.

Apparatus. The participants were seated in a dimly lit room in front of a color cathode-ray monitor (1280x1024 pixels, retrace rate 85 Hz) at a viewing distance of approximately 70 cm.

Stimuli and procedure. Four different categories of grayscale images (spiders, snakes, mushrooms, and flowers), each containing thirty-five different pictures (4.16° of visual angle; 1 mm ≈ 0.008° of visual angle), were presented against a lighter gray background (8.75 cd/m^2). Each trial started with the appearance of the central fixation point. After a varying delay, the prime was displayed for 24 ms either above or below the fixation point at a distance of 3.74°. Subsequently, the two targets were presented to the left and right side of the prime at prime-target SOAs of 35 or 105 ms and remained on screen until the participant's response. In half of the sessions, targets were accompanied by a pink-noise mask that occurred at the same position as the prime. The masks were generated by a Matlab program written by Yearsley (2004) and based on inverse Fourier transformations. In each trial, the prime was either consistent or inconsistent to the target with respect to the required response. All stimulus combinations of prime and target picture categories and prime-target SOA occurred equiprobably and pseudo-randomly in a repeated-measures design.

In the first 4 sessions, the participants completed the target identification tasks (i.e., they had to classify the target as fast and as accurately as possible) and received immediate feedback on correctness of their responses. In the next 4 sessions, they

completed the prime identification tasks (i.e., they had to indicate the prime as accurately as possible).[11] As in Experiment 1 (Chapter 2), in the target identification sessions, participants either discriminated spiders and snakes from flowers and mushrooms *("animal vs. non-animal" task)* or spiders and mushrooms from snakes and flowers *("spider/mushroom vs. snake/flower" task)*. In the prime identification sessions, participants were presented with exactly the same experimental paradigm only that now they had to categorize the prime according to the respective categorization task. For example, in the "animal vs. non-animal" task, they had to report if the prime picture contained an "animal", (i.e., a spider or a snake), or a "non-animal", (i.e., a flower or a mushroom). They were told that the speed of their response was irrelevant. Response keys were counterbalanced across participants, and they again received immediate auditory feedback. Each session started with one practice block followed by 29 blocks of 32 trials. Participants were debriefed after the final session and received an explanation of the experiment.

At the end of the final session, participants were asked to evaluate the images of spiders, snakes, mushrooms, and flowers applied in the study. The rating involved three dimensions (valence, arousal, and disgust). All dimensions were rated on a six-point rating scale. Scales were coded so that high scores reflected high arousal and disgust, respectively. Positive scores in the valence ratings represented positive feeling towards the image; a score of zero meant that no positive or negative feelings were involved; negative scores reflected negative feelings (Table 2). The rating was conducted to ensure that phobic pictures did indeed elicit negative emotions in spider-fearful participants. As expected, non-anxious controls and spider-fearful subjects differed significantly regarding their evaluations. Control participants rated all pictures of spiders, snakes, flowers and mushrooms as minimally arousing, minimally disgusting and of neutral valence. As expected, spider-fearful participants rated spider pictures as strongly arousing, strongly disgusting and strongly negative compared to snake, flower and mushroom images. This was reflected in the results of a multivariate analysis of

[11] Note that the only difference between target and prime identification task were the respective instructions given to the participants. This is a precondition for avoiding task mismatches which would complicate a conjoint interpretation of both tasks' findings (e.g., Schmidt & Vorberg, 2006).

variance (MANOVA) with factors of group *(G)* and picture category *(PC)* (Wilk's Λ = 0.62, F_{GxPC}(9, 131.57) = 3.14, p = .002).

Table 2: Participants' mean scores (with standard deviations) for image evaluation separately for scale (valence, arousal, and disgust) for each picture category and each group. Bold letters indicate phobic image categories.

	Arousal				Disgust				Valence			
	Spider	Snake	Mushroom	Flower	Spider	Snake	Mushroom	Flower	Spider	Snake	Mushroom	Flower
Controls	1.30 (1.49)	0.75 (1.01)	0.71 (1.17)	0.42 (0.72)	1.64 (1.80)	0.54 (0.96)	0.73 (1.26)	0.00 (0.00)	-0.46 (1.25)	-0.02 (1.00)	-0.11 (0.92)	1.02 (1.00)
Spider Fear	**3.93 (1.49)**	1.23 (1.12)	0.46 (0.73)	0.32 (0.75)	**4.69 (1.31)**	1.21 (1.26)	0.62 (1.00)	0.24 (0.68)	**-2.52 (0.63)**	-0.41 (0.97)	-0.37 (0.77)	0.70 (0.92)

Data treatment and statistical methods. Practice blocks were not analyzed. In the target identification task, trials were eliminated if response times were shorter than 100 ms or longer than 1000 ms, and if, incidentally, prime and target were the same image. These criteria eliminated 1.93% of trials in the "animal vs. non-animal" task and 2.76% of trials in the "spider/mushroom vs. snake/flower" task. In the prime identification task, trials were only eliminated if prime and target were the same image. This criterion eliminated 0.83% of trials in the "animal vs. non-animal" task and 0.91% of trials in the "spider/mushroom vs. snake/flower" task. Repeated-measure analyzes of variance (ANOVAs) were performed with Greenhouse-Geisser-corrected p values. Analyzes of response times are restricted to trials on which participants made correct responses. Additionally, we report error rates. Error rates were arc sine transformed to make them compatible with ANOVA requirements. We report F values with subscripts indicating the respective effect (e.g., F_{cxS} for the interaction of consistency and SOA).

3.3. Results

The results section will be structured as follows. We will first analyze the data of the *target identification task* and examine the *influence of the different targets* on overall response times as a measure of response activation by the different targets (spider, snakes, mushrooms, flowers) as well as the *influence of the different primes on response priming effects* as a measure of response activation by the primes. Secondly, we will analyze and compare the performance in the *prime identification task* for the two groups.

3.3.1. Target identification task

Influence of the targets on overall response times. In this ANOVA, we look at overall response times (averaged across consistent and inconsistent primes) as a measure of response activation by the four different targets (spider, snake, mushroom, and flower). The analysis of the interaction of group *(G)* and target *(T)* was significant ($F_{GxT}(3,42) = 3.65$, $p = .040$; for error rates: $F_{GxT}(3,42) = 0.86$, $p = .440$) confirming that target response time effects differed systematically between groups. To analyze this result in more detail, we performed an ANOVA for each group with factors target *(T)*, consistency *(C)*, and SOA (*S*) (because consistency and SOA effects are not of theoretical interest at this point, we will not report them). In the non-anxious control group, only responses to snake targets were slower compared to other targets ($F_T(3,21) = 4.59$, $p = .030$; for error rates: $F_T(3,21) = 2.95$, $p = .078$; Fig. 10).[12] Importantly, though, spider-fearful participants responded considerably faster to spider pictures ($F_T(3,21) = 9.26$, $p = .008$; for error rates: $F_T(3,21) = 7.02$, $p = .011$). We conducted paired comparisons of spider targets and the other target picture categories and observed significant differences in each contrast for spider-fearful participants (spider vs. snake: $F_T(1,7) = 11.87$, $p = .011$; spider vs. mushroom: $F_T(1,7) = 7.82$, $p = .027$; spider vs. flower: $F_T(1,7) = 7.16$, $p = .032$). Numerically, responses on spider targets were on average about 25 ms faster compared to responses to other targets.

[12] Note that response times to targets in the group of control participants are in general about 43 ms faster than in the experimental group of spider-fearful participants. This effect seems to be base on interindiviual differences of participants in the two groups (i.e., non-anxious control participants responded faster in general).

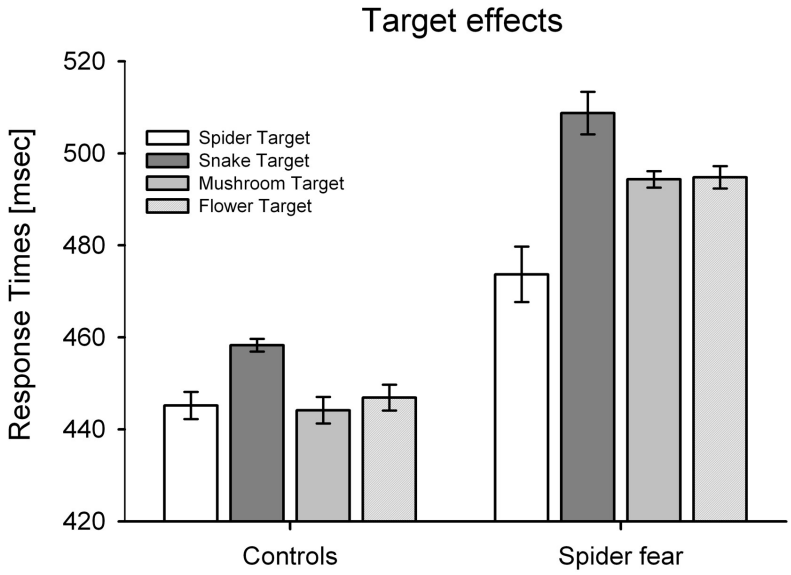

Fig. 10. Relative response times to the four target picture categories for both groups averaged over both tasks.

Influence of the primes on response times. Response times of both groups separated by task and prime category are displayed in Figure 11. Generally, in almost every panel, consistent trials produced considerably faster response times than inconsistent trials in the "animal vs. non-animal" as well as in the "spider/mushroom vs. snake/flower" task (*controls*: $F_C(1,7) = 116.66$ and 46.41, both $p < .001$; for error rates: $F_C(1,7) = 44.73$ and 15.23, $p < .001$ and $p = .006$; *spider fear*: $F_C(1,7) = 88.93$ and 61.44, both $p < .001$; for error rates: $F_C(1,7) = 33.95$ and 64.75, $p = .001$ and $p < .001$). Overall, these priming effects strongly increased with prime-target SOA in both groups and tasks (*controls*: $F_{CxS}(1,7) = 46.20$ and 29.58, $p < .001$ and $p = .001$; for error rates: $F_C(1,7) = 39.90$ and 10.94, $p < .001$ and $p = .013$; *spider fear*: $F_{CxS}(1,7) = 19.86$ and 20.73, both $p = .003$; for error rates: $F_C(1,7) = 21.19$ and 26.81, $p = .002$ and $p = .001$).

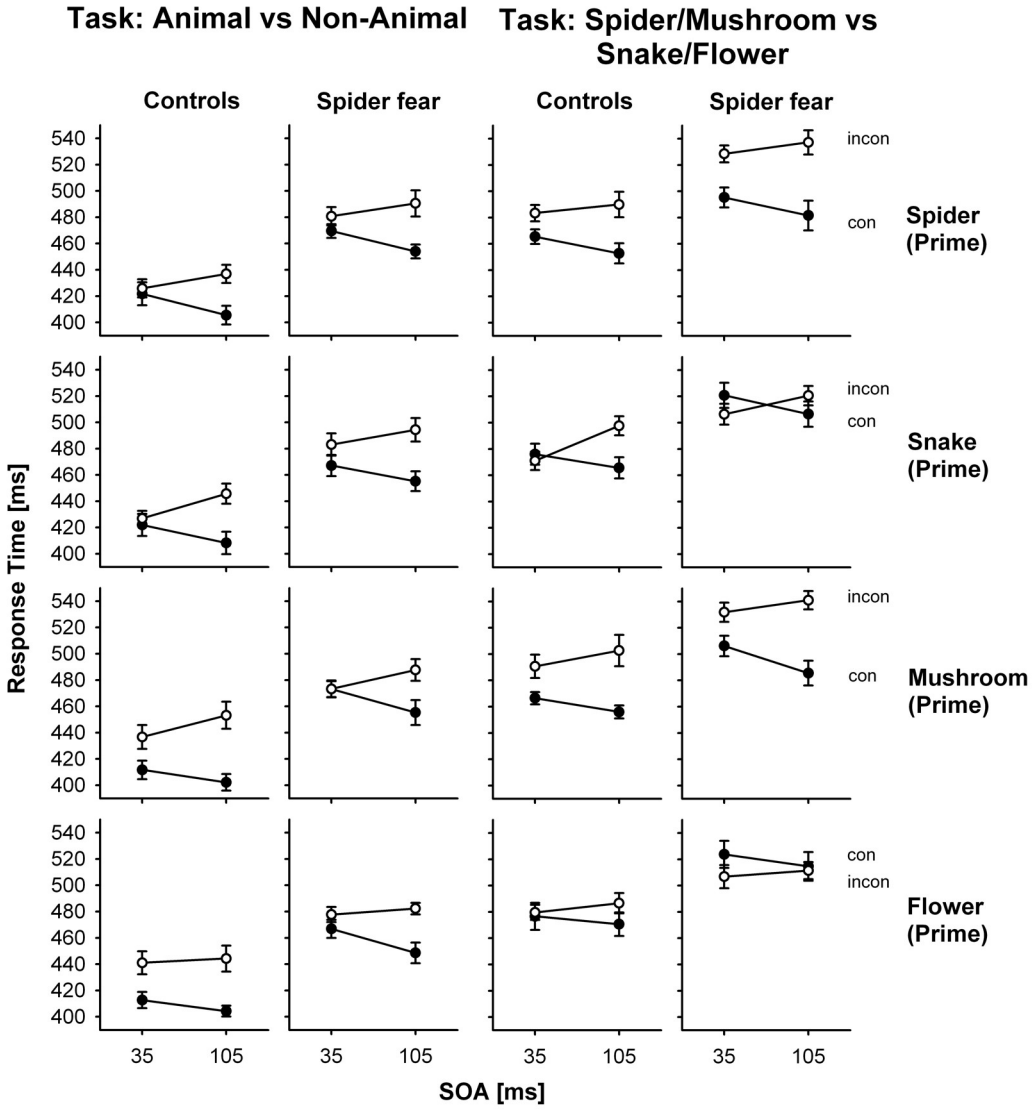

Fig. 11. Response times in the two tasks for each group separated by primes.

In the following, we will report the results separately for each task and each group and highlight eventual differences.

In the "animal vs. non-animal" task, priming effects of non-anxious control participants were the same for each prime picture category ($F_{PxC}(3,21) = 2.77$, $p = .120$; for error rates: $F_{PxC}(3,21) = 1.08$, $p = .363$). Also, threat-relevant primes (spiders and snakes) did not lead to larger priming effects than neutral primes (mushrooms and flowers) ($F_{PxC}(1,7) = 3.34$, $p = .108$; for error rates: $(F_{PxC}(1,7) = 0.03$, $p = .866$). In spider-fearful participants, priming effects were also of the same magnitude, independent of prime category ($F_{PxC}(3,21) = 0.59$, $p = .553$; for error rates: $F_{PxC}(3,21) =$

0.06, p = .915) or prime response category (i.e., spider/snake vs. mushroom/flower; $F_{PxC}(1,7) = 0.52$, p = .493; for error rates: $F_{PxC}(1,7) = 0.04$, p = .854). Consistently, an ANOVA including the factor group yielded no significant interaction of that factor and consistency.

In the *"spider/mushroom vs. snake/flower" task,* non-anxious controls again showed no differences between priming effects neither for the four prime categories ($F_{PxC}(3,21) = 3.30$, p = .094; for error rates: $F_{PxC}(3,21) = 0.55$, p = .508) nor for the prime response categories (here: spiders/mushrooms vs. snakes/flowers) ($F_{PxC}(1,7) = 4.03$, p = .085; for error rates: $F_{PxC}(1,7) = 1.52$, p = .561). In contrast, the priming effects in spider-fearful participants differed significantly across prime categories ($F_{PxC}(3,21) = 6.38$, p = .035) as well as across prime response categories ($F_{PxC}(1,7) = 6.71$, p = .036). However, the effect was not reflected in error rates (prime categories: $F_{PxC}(3,21) = 0.90$, p = .395; prime response categories: $F_{PxC}(1,7) = 0.80$, p = .402). To analyze the response time effects of the spider-fearful participants in more detail, we compared them for the different target picture categories (Fig. 12). The figure clearly illustrates that the group of spider-fearful participants responded more rapidly to spider targets in both tasks almost independent of prime-target consistency. An ANOVA with the additional factor of participant group *(G)* showed that priming effects across prime response categories were indeed of different magnitudes in the two groups ($F_{GxPxC}(1,14) = 7.11$, p = .018). This effect did not reach significance in error rates ($F_{GxPxC}(1,14) = 0.05$, p = .828).

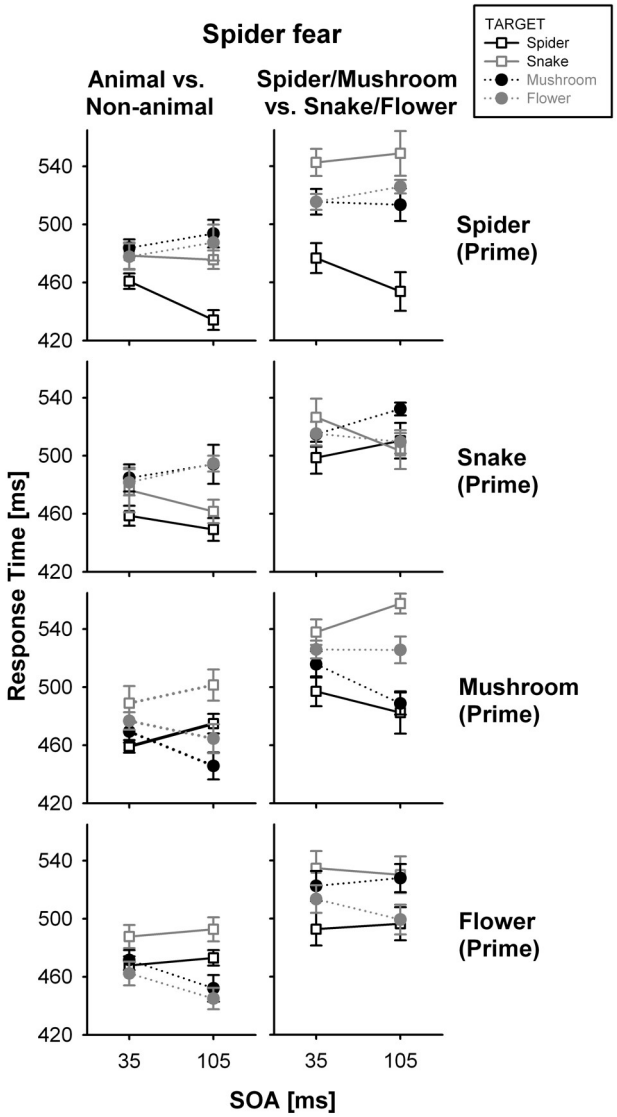

Fig. 12. Response times of spider-fearful individuals in the "animal vs. non-animal" and "spider/mushroom vs. snake/flower" tasks separated by primes. Lines of consistent and inconsistent trials are separated by targets.

Comparing the two tasks. A main effect of task (*Ta*) was observed within each group (*controls:* $F_{Ta}(1,7) = 11.56$, $p = .011$; for error rates: $F_{Ta}(1,7) = 11.52$, $p = .012$; *spider fear:* $F_{Ta}(1,7) = 12.49$, $p = .010$; for error rates: $F_{Ta}(1,7) = 0.33$, $p = .584$). Participants responded up to 50 ms slower in the "spider/mushroom vs. snake/flower" task, most probably because cognitive demands were higher in this task. Specifically, in the "animal vs. non-animal" task, the response categories are consistent with an intuitive natural categorization of objects, whereas in the "spider/mushroom vs. snake/flower"

task, participants initially had to learn which pictures belong to which response category.

3.3.2. Prime identification task

For statistical analysis, we conducted an ANOVA with factors of mask *(M)*, prime *(P),* and group *(G)* and, surprisingly, observed no main effect of the mask ($F_M(1,14) = 3.81$, $p = .071$) (i.e., the number of correct responses in the masked trials did not differ from those in the unmasked trials). We assume that this was a result of our experimental design: As described in detail in the method section, the prime was always followed by two flanking targets. In the masked trials, a pink-noise mask appeared on the same position as the prime together with the targets, which should have decreased the prime's visibility. However, it might be that the two targets already acted as backward masks in the unmasked trials because of their immediate vicinity to the prime. Hence, the visibility of the primes (and the identification performance) was decreased not only in the masked trials but also in the "unmasked" trials in a similar manner. The pink-noise mask could not further add to the target-induced masking. Thus, in the following, we report the prime identification data averaged over masked and unmasked trials.

Additionally, we observed no interaction effect of prime *(P)* and group *(G)* ($F_{PxG}(3,42) = 1.40$, $p = .264$) meaning that in contrast to our expectations the groups had the same prime identification performance. Surprisingly, when analyzing performance separately for each group (ANOVA with factors of prime *(P),* consistency *(C)*, and SOA (*S*)) we observed a main effect of prime category in the control group but not in the spider-fearful group (*controls:* $F_P(3,21) = 20.08$, $p < .001$;[13] *spider fear:* $F_P(3,21) = 1.36$, $p = .288$). These results are in contrast to our expectations because we assumed that spider-fearful participants would be *better* at identifying their fear-relevant spider primes compared to the snake, mushroom, and flower. However, they tended to be slightly worse in doing so (correct responses to spider primes: $m = 0.64$ ($sd = 0.48$), snake primes: $m = 0.70$ ($sd = 0.46$), mushroom primes: $m = 0.69$ ($sd = 0.46$), flower primes: $m = 0.72$ ($sd = 0.45$), Fig. 13).

[13] Correct responses of control participants to spider primes: $m = 0.70$ ($sd = 0.46$), snake primes: $m = 0.77$ ($sd = 0.42$), mushroom primes: $m = 0.79$ ($sd = 0.40$), flower primes: $m = 0.75$ ($sd = 0.43$).

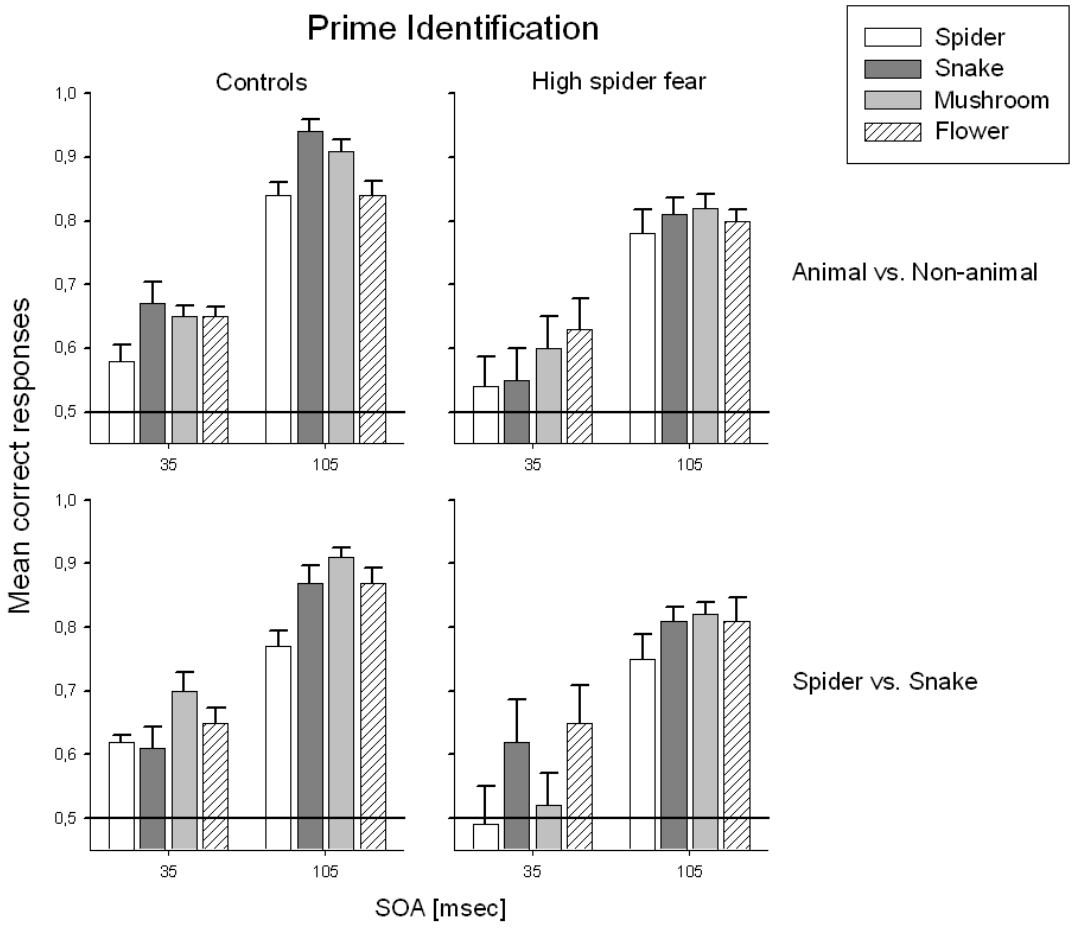

Fig. 13. Mean correct responses in the prime identification task separated by group, task, prime, and SOA.

To explain the results, we call attention to one characteristic of the prime identification task. In contrast to the target identification task in which participants were asked to react as fast as possible, participants had no time pressure. As discussed in Section 1.5. "Attentional biases in specific phobias", spider phobics show an attentional bias towards spiders within the first 500 ms that is followed by intentional avoidance. In contrast to the target identification task where early and automatic information processing is measured, the prime identification task is aimed at measuring the visual awareness of the primes. Certainly, the involved processes and also the participants' responses are comparatively slow and, therefore, allow for non-automatic response biases. To test this hypothesis, we searched our data for such response biases and,

indeed, observed that spider-fearful participants tended to use the response category which included the spider primes more rarely. For example, in the "spider vs. snake" task, spider-fearful participants declared in 54 percent of the cases that they had seen a snake or a flower and only in 46 percent that they had seen a spider or a mushroom (compared to 50 percent actual appearances). In contrast, non-anxious control participants used both response categories equally often (Table 3). That finding might to a certain degree explain the results of the spider-fearful group: if a spider-fearful participant by trend avoids the categories which include spider pictures, his or her performance can never reach 100 percent. However, it must be noted that the response bias in the spider-fearful group was comparably small and cannot entirely explain why our expectations were not met.

Table 3: Relative frequency of responses for the respective response category for non-anxious control and spider-fearful participants.

		Category which *includes* spider pictures	Category which *excludes* spider pictures
Controls	„Animal vs. Non-animal" task	0.50	0.50
	„Spider/Mushroom vs. Snake/Flower" task	0.50	0.50
Spider Fear	„Animal vs. Non-animal" task	0.48	0.52
	„Spider/Mushroom vs. Snake/Flower" task	0.46	0.54

3.4. Discussion

To investigate the role of phobia in image processing, we analyzed systematic differences between response patterns of the two groups of participants. Such differences were evident in the overall response times (reflecting processing aspects of the target) as well as in the magnitude of priming effects in response times (reflecting processing aspects of the prime).

In almost all experimental conditions inconsistent trials led to slower response times compared to consistent ones, and these priming effects increased with prime-target SOA. These findings show that natural images can rapidly activate motor responses assigned to them and are in line with previous results from the image categorization literature (e.g., Bacon-Macé et al., 2007; Kirchner & Thorpe, 2006) as well as from response priming studies with natural images (Schmidt & Schmidt, 2009).

Surprisingly, we found that snake targets had a peculiar influence on response times: Participants responded somewhat slower to them compared to spider, mushroom, and flower targets. However, because this response pattern was observed in both groups, we conclude that it rather be based on physical characteristics of the snake pictures than on emotional significance of snake pictures.[14] Also, priming effects in the non-anxious control group were not systematically different for the four prime categories, neither in the "animal vs. non-animal" nor in the "spider/mushroom vs. snake/flower" task. Instead, depending on their consistency to the targets, primes always produced strong and reliable priming effects. This illustrates the way in which our paradigm controls for low-level image characteristics. By comparing the two groups and also the two tasks, we can identify and dispose of effects induced by these characteristics. In line with our previous findings (see Experiment 1, Chapter 2), we observed no advantages for threat-relevant images (spiders and snakes) on information processing in non-anxious controls, neither on response times to spider and snake targets nor in priming effects when spiders or snakes preceded the target.

In contrast, spider-fearful participants showed a unique response pattern, comparable to the results in Experiment 1. They responded more rapidly to spider targets compared to snake, mushroom and flower targets, leading to increased priming effects in those response categories that included the spider images. This effect can most clearly be seen in the second task (cf. Experiment 1).

Furthermore, we expected that spider-fearful participants would be better at identifying briefly presented spider primes compared to non-anxious control participants. One of the main conclusions of Experiment 1 was that enhanced

[14] This conclusion is supported by the image ratings. Control participants rated the snake pictures comparable to the neutral images of mushrooms and flowers. Although the spider-fearful group rated snakes as slightly more disgusting and arousing compared to mushrooms and flowers, these ratings were not as high as the scores on the dimensions "arousal" and "disgust" to spider images.

information processing of threat-relevant stimuli might be due to life-long perceptual learning processes. More specifically, we concluded that neurons of spider-fearful individuals are specialized in processing spiders (cf. Section 6.3.2. "The neural basis of perceptual learning"). One could speculate that the same neuronal networks would not only allow for faster identification but would also help in detecting spiders in our environment. However, we did not find such an effect in our data. In the group of spider-fearful participants all prime categories were identified equally well, falsifying our hypothesis. Additionally, spider-fearful participants were less correct for all prime categories in the prime identification task. However, I assume that this is due to a general effect. As mentioned in the results section, spider-fearful participants were also slower in their responses in the target identification task compared to the non-anxious control group. Given the fact, that the two groups were instructed by two different experimenters we can not rule out that different manners of instructions given to the participants biased our results leading to worse performance in the experimental group.

Our main result (i.e., enhanced information categorization of phobic images, but no improved performance in identifying phobic images) might be explained by the fact that the type of information processing measured in the target identification task differs from that measured in the prime identification task. Although long-term perceptual learning processes in spider-fearful individuals might speed their visuomotor responses to spiders, this learning does not necessarily lead to an improved performance in the detection of spiders in the environment. In line with this assumption, a large number of studies demonstrated a dissociation between visuomotor processes and visual awareness (e.g., varied by different masking strength; Fehrer, & Raab, 1962; Klotz, & Neumann, 1999; Klotz & Wolff, 1995; Schmidt & Schmidt, 2010; Vorberg et al., 2003). Importantly, these findings imply that categorization effects as measured by response priming effects are based on different mechanisms compared to the identification of masked primes (Schmidt & Vorberg, 2006). For example, this was illustrated by a response priming study in which the appearance of dark and bright primes was altered by a visual illusion (Schmidt et al., 2010). The authors showed that the priming effects depended only on local flanker–background contrast, not on the subjective appearance of the primes: indeed, a prime could appear (relatively) bright but could prime as if it were (relatively) dark (see also Schmidt, Haberkamp, Veltkamp et al., 2011 for a

summary and discussion). But what are the underlying mechanisms of stimulus categorization and stimulus identification?

Rapid stimulus categorization is assumed to rely on more basic information processing (e.g., local contrast of a stimulus) and is processed within the first feedforward sweep of neuronal activation (cf. Section 1.4.2. "The rapid-chase theory of response priming") and might base on preconscious visual processing (Lamme & Roelfsema, 2000; also see Bullier, 2001). In contrast, identification of a stimulus requires visual awareness, needs an integrated reconstruction of the scene and, therefore, recurrent feedback from separate cortical areas (Roelfsema, 2006). Importantly, our results do not not necessarily question the assumption that perceptual learning processes speed up processing of phobic animals. In contrast, neuronal changes induced by perceptual learning might enhance information processing of briefly presented primes without facilitating the conscious percept of those stimuli. Also, from an evolutionary point of view, it might be more plausible that spider-fearful individuals are not better in identifying shortly masked spider pictures but partly occluded spider pictures (similar to real-world spiders hiding in the woods; Öhman & Mineka, 2001). That would mean that a prime identification task would not adequately address the question how spider-fearful individuals profit from trained neurons on detecting spiders. On these grounds, it would be interesting to test for different potential consequences of that specific neuronal hardware in future studies.

To sum up, an explanation of our results (i.e., enhanced information processing of phobic images, but no improved performance in identifying phobic images) would be that the type of information categorization measured in the target identification task differs from that measured in the prime identification task. As a consequence, also the neuronal hardware underlying the performance in the two tasks is most probably different. Therefore, although spider-fearful individuals respond faster to spiders due to long-term perceptual learning processes, this neural plasticity does not automatically lead to an improved performance in the identification of spiders in the environment.

4. Experiment 3 - Information processing is enhanced in blood-injury-injection fear: Evidence from a response priming study

4.1. Introduction

As described in Section 1.4. “Enhanced information processing in specific phobias” and 1.5. “Attentional biases in specific phobia”, information processing of phobic stimuli is enhanced in individuals with animal phobia. Furthermore, phobic stimuli are able to modulate attention in phobic individuals. The large number of studies showing these effects suggests that the repeatedly shown vigilance towards phobic or threat-relevant stimuli, respectively, exists roughly alike in the majority of individuals with any anxiety disorder. To the best of our knowledge, few studies specifically compared participants with different types of anxiety disorders. Indeed, the results for the different groups were usually comparable. For example, Ehlers and Breuer (1995) conducted an experiment using a modified Stroop task and observed that participants with specific phobias as well as participants with panic attacks comparably shifted their attention towards the phobic and threat-relevant stimuli, respectively. Öhman and colleagues’ (2001) asked non-anxious control, spider phobic, and snake phobic participants in a visual search task to search for pictures of spiders or snakes in grid-pattern arrays of flower and mushroom pictures, and vice versa. They found that threat-relevant pictures of spiders and snakes were found more quickly than neutral pictures by all three groups, with even faster responses to phobic stimuli in the two phobic groups (also cf. Teachman, Gregg, & Woody, 2001; Wenzel & Holt, 1999).

However, in Experiment 1 (Chapter 2), we observed marked differences between spider- and snake-fearful participants. In line with these findings, Soares, Esteves, Lundqvist, and Öhman (2009) reported that spider-fearful participants were specifically faster in detecting spiders compared to fear-relevant but non-phobic snakes and neutral targets in a visual search task. But in snake-fearful participants, they observed no differences in performance between snakes and fear-relevant but non-phobic spiders.

From these results, we concluded that information processing might differ in different types of specific phobias. Within the class of specific phobias, there is one type that especially differs from the other specific phobias; that is blood-injury-injection

(BII) phobia. In BII phobia, individuals sense an extreme and irrational fear of blood, injuries, or receiving an injection or an invasive medical procedure (Öst, 1992). This phobia lends itself to investigation due to 3 reasons: (1) BII phobia has distinct features that distinguish it from all other specific phobias (e.g., animal phobias); (2) few studies have investigated the speed of information processing in individuals with BII phobia compared to the large number of studies focusing on animal and social phobia; (3) these studies produced mixed results; Thus, it remains unclear if BII-fearful individuals exhibit enhanced information processing or an attentional bias similar to that in other phobias.

First of all, up to 70% of BII phobics report a history of fainting due to a marked drop in blood pressure, heart rate, or both when confronted with their phobic stimuli (i.e., blood or injections; Öst, 1992). In contrast, in other specific phobias (e.g., animal phobia) exposure typically triggers sympathetic reactions, for instance, panic-related symptoms like sweating, trembling, and an increased heart rate and blood-pressure (Antony, Brown, & Barlow, 1997). Furthermore, individuals with BII phobia frequently avoid medical procedure which might lead to serious health implications (Öst, 1992). Therefore, Armstrong, Hemminger, and Olatunji (2013) argue that research should contribute to develop more effective treatments for BII-fearful individuals. According to the authors, one promising area is that of studying vigilance in BII-fearful individuals since the early attentional biases contribute to the increased distress when they are confronted with a phobic stimulus (Weierich, Treat, & Hollingworth, 2008).

Despite that the attentional bias towards threat-relevant stimuli is a core feature of other specific phobias; the evidence for an attentional bias in BII fear is equivocal. For example, Sawchuk, Lohr, Lee, and Tolin (1999) used a Stroop task to compare semantic information processing in BII phobic and non-phobic control participants. 10 medical (e.g., “injection”), 10 disgust (e.g., “vomit”), 10 negative (e.g., “lonely”) and 10 neutral words (e.g., “spoon”) were randomly presented in black, blue, green, or red. The authors measured color-naming latencies of BII phobics and control participants on medical and disgust words and found no difference between the two groups. This indicates that no attentional bias in BII phobics towards phobic stimulus material exists. In line with these findings, Wenzel and Holt (1999) showed in a dot probe task that individuals with BII phobia did not exhibit an attentional bias towards their phobic

stimuli. However, both studies are limited by the fact that they used lexical stimuli which might not be strong enough to elicit an attentional bias in BII-fearful participants (Armstrong et al., 2013).

This limitation was overcome in a series of experiments that were conducted more recently by Buodo and colleagues. In their eye-tracking study, BII-fearful and control participants were shown phobic, positive emotional and neutral pictures (Buodo, Sarlo, Codispoti, & Palomba, 2006). The authors measured free viewing times and event-related potentials (ERPs). (1) the eye-tracking results revealed no clear pattern of visual avoidance in BII-fearful participants: Even though these participants spent less time looking at blood pictures when compared to control participants (i.e., between groups comparison), they did not spend less time looking at blood pictures compared to the other picture categories (i.e., within group comparison). That means phobic pictures were not specifically shunned by BII-fearful individuals. (2) the ERPs amplitudes of BII-fearful participants revealed neither an increase indicating an attention bias towards the phobic stimuli nor a decrease indicating avoidance of the phobic stimuli. The authors concluded that BII-fearful individuals show no vigilance-avoidance pattern.

In a follow-up study, the authors measured magnetoencephalography(MEG)-activity in BII-fearful and non-anxious control participants in response to phobic and non-phobic pictures (Buodo, Peyk, Junghöfer, Palomba, & Rockstroh, 2007). They found a higher activation in BII-fearful participants for the two picture categories of phobic and neutral stimuli, but not specifically for phobic pictures. Again, they interpreted these findings as evidence that phobic stimuli are not preferentially processed by BII-fearful individuals.

However, there is also evidence that BII phobia is associated with a vigilance-avoidance pattern. Tolin, Lohr, Lee, and Sawchuck (1999) used a viewing paradigm and showed that BII phobics avoided viewing injection images compared to non-anxious controls and spider phobics. Mogg and colleagues (2004) found the same effect for BII-fearful in participants in a visual dot probe task. In addition, the authors showed that an intentional avoidance was preceded by an initial vigilance for phobic stimuli. Finally, two studies by the group of Buodo and colleagues contradicted the group's earlier results. Buodo, Sarlo, and Munafò (2010) investigated the N2pc component of ERPs - which is assumed to reflect processes of spatial attention - in BII-fearful and non-

anxious control participants and found an attentional bias followed by visual avoidance. Subsequent, Sarlo, Buodo, Devigili, Munafò, and Palomba (2011) induced cognitive-emotional sensitization in BII-fearful participants by repeatedly presenting the same pictures of blood and mutilation, randomly interspersed with neutral images. They observed an early attentional bias, indicated by larger early N100 potentials, in the group of BII phobics compared to controls, followed by attentional avoidance reflected in smaller late positive potentials.

There is even one study that reports an attentional bias but not in line with the vigilance-avoidance theory. In an eye-tracking study by Armstrong and colleagues (2013), BII-fearful participants showed a robust vigilance-avoidance pattern. However, although, BII-fearful participants oriented their attention more often to injection images and avoided them subsequently compared with non-anxious control participants, they did not attend to those images more frequently compared to other emotional images. These results imply that BII-fearful individuals respond more intensely to emotional images per se, but not specifically to phobic images.

In sum, the existence of enhanced information processing and/or an attentional bias for phobic stimuli in BII phobic individuals is equivocal. Here, we provide further evidence for an advantage in information processing for phobic images in BII phobia by applying a response priming paradigm (cf. Section 1.4.1. "The response priming paradigm"). We chose to employ images of small injuries plus control images of unharmed body parts. These pictures of small injuries represent *phobic* stimuli for BII-fearful participants, but merely *threat-relevant* stimuli for the non-anxious control participants. The control pictures represent *neutral* stimuli for both groups. We assumed that highly arousing pictures of severe mutilations would also evoke strong reactions in the non-anxious control participants, so that possible differences between them and the BII-fearful group would be difficult to detect. In contrast, minor injuries, which are frequently encountered in everyday life, should elicit strong emotional reactions only in the BII-fearful but not in control participants.

In the present experiment, one prime and one target were presented in rapid sequence, and participants classified the targets as quickly as possible by pressing one button for injury pictures and another button for neutral pictures. We hypothesized that the BII-fearful participants will show an information processing advantage (possibly

caused by an early attentional bias). This will be expressed in larger priming effects by injury primes, as compared to neutral image material (within group comparison) and to non-anxious control participants (between group comparison) and faster responses to injury targets (within group and between group comparison).

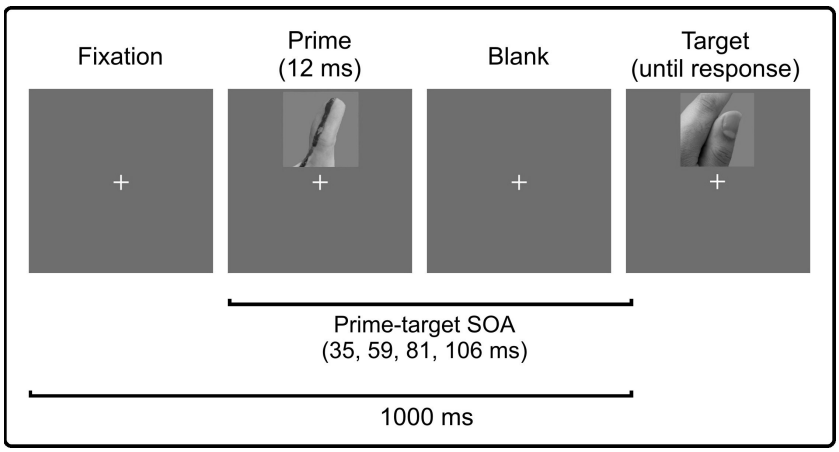

Fig 14. Stimuli and Procedure. Primes and targets were presented in the sequence displayed. Targets acted as backward masks for preceding primes. In each trial, the prime was either consistent or inconsistent to the target. Note that the original images were presented in color against a light gray background.

4.2. Methods

Participants. Fifty-one participants recruited, through the University of Kaiserslautern, took part in the experiment. All of them were naïve to the purpose of the study. All participants were screened for fear of blood, injury and injections before the experiment started (Table 4). For this purpose, we applied two blood-injury-injection-questionnaires (German version of the "Multidimensional Blood/Injury Phobia Inventory" MBPI; Gebhardt, Kämpfe-Hargrave, & Mitte, 2010; German version of the "Mutilation Questionnaire" MQ; Hamm, 2006; original version by Klorman et al., 1974).

In addition, BII-fearful participants were tested for specific anxiety disorders using a structured diagnostic interview ("Diagnostic Interview for Psychological Symptoms (DIPS)"; Schneider & Margraf, 2006), based on the DSM-IV-TR (APA,

2000). All participants met at least four of the six criteria for specific phobias. The criterion that was not satisfied in most cases (criterion E) states that the individual's fear, anxiety, or avoidance causes significant distress or interference in the person's day-to-day life. For this reason, we will refer to the participants in the experimental group as "fearful" instead of "phobic".

BII-fearful participants had to score above the cut-off score of the MBPI of 48. Control participants had to score below 48 in the MBPI and below percentile 25 in the MQ. Out of the 51 participants, 42 met the inclusion criteria, whereas the data from one BII-fearful and 8 control participants had to be excluded: seven control participants scored too high in the MQ-questionnaire; one BII-fearful and one control participant, were excluded due to technical problems with data recording. The data of nineteen BII-fearful participants (16 women and 3 men; mean age = 24.2 years) and twenty-three non-anxious control participants (15 women and 8 men; mean age = 24.7 years) were analyzed.

Table 4: Means (SDs) for group characteristics.

	BII-Fear	Controls	t (40)	*p*
Measure				
MBPI	77.63 (25.03)	9.30 (6.15)	11.61*	$p < .001$
MQ	20.68 (5.85)	5.87 (6.22)	7.89	$p < .001$
Age	24.16 (2.65)	24.74 (5.80)	-.40	*ns*
Image rating				
Injury - Arousal	**3.03 (1.32)**	.57 (.51)	7.68	$p < .001$
Injury - Disgust	**3.39 (1.18)**	.74 (.50)	9.15	$p < .001$
Injury - Valence	**-1.77 (.82)**	-.57 (.44)	-5.17*	$p < .001$
Neutral - Arousal	.47 (.73)	.03 (.06)	.98*	*ns*
Neutral - Disgust	.26 (.39)	.03 (.06)	2.57*	$p = .019$
Neutral - Valence	.49 (1.21)	.18 (.33)	2.60*	$p = .018$

Note: Ratings on 6-point Likert scale (for valence ratings: -3 = „extremely unpleasant", 3 = "extremely pleasant"; for all other ratings 0 = "not at all", 6 = "extremely"); *ns* = non significant; MBPI = Multidimensional Blood/Injury Phobia Inventory; MQ = Mutilation Questionnaire; bold letters indicate responses to phobic stimuli. *degrees of freedom adjusted due to unequal variance.

Participants had normal or corrected-to-normal visual acuity and received payment of 6 € per hour. All of them gave written informed consent and were treated in

accordance with the ethical guidelines of the American Psychological Association. Some BII-fearful participants accepted the offer to inspect example images before deciding to participate.

Apparatus. The participants were seated in a dimly lit room in front of a color cathode-ray monitor (1280x1024 pixels, retrace rate 85 Hz) at a viewing distance of approximately 70 cm.

Stimuli and Procedure. Two different categories of colored images (pictures of injuries and pictures of unharmed body parts), each containing forty-one different pictures (4.23° of visual angle; 1 mm ≈ 0.008° of visual angle), were presented against a lighter gray background (8.75 cd/m^2). Pictures of injuries and unharmed body parts were matched, such that an equivalent number of injured body part pictures and unharmed body part pictures (e.g.,hands, legs) were presented. Matching the pictures makes between group comparisons more reliable because neutral and threat-relevant/phobic pictures do not differ in picture content. To the best of our knowledge, this was not done in previous studies with BII-fearful participants.

Each trial started with the appearance of the central fixation point. After a varying delay, the prime was displayed for 12 ms either above or below the fixation point at 3.74° eccentricity. Subsequently, the target was presented at the same position at prime-target SOAs of 35, 59, 81, or 106 ms and remained on screen until the participant's response (cf. Fig. 14). The time from fixation onset to target onset was constant at 1000 ms. In each trial, the prime was either consistent or inconsistent with the target with respect to the required motor response. All stimulus combinations of prime and target picture categories and prime-target SOA occurred equiprobably and pseudo-randomly in a repeated-measures design.

Participants categorized the targets as quickly as possible by pressing the left button for threat-relevant pictures and the right button for pictures of unharmed body parts (or vice versa). The assignment of left and right response keys was counterbalanced across participants. Participants received summary feedback on the speed and correctness of their responses after each block. Each participant performed one 1-hour session. That session started with one practice block followed by 17 blocks of 32 trials. Finally, participants completed an image rating (see below) and received an explanation of the experiment.

Participants were asked to evaluate all test images of injured and unharmed body parts. The rating involved three dimensions (valence, arousal, and disgust) that were each rated on a six-point rating scale. Scales were coded so that high scores reflected high arousal and disgust, respectively. In the valence dimension, possible ratings ranged from negative to positive emotion. Five control and three fearful participants misunderstood instructions and rated unharmed body parts as highly negative. Their valence ratings were excluded from further analysis.

Non-anxious controls and BII-fearful participants differed significantly regarding their evaluations (Table 4). A multivariate analysis of variance (MANOVA) with factors of group and picture category and the three rating scales as dependent variables confirmed a main effect of group, with BII-fearful participants rating pictures as more negative, arousing, and disgusting compared to control participants (Wilk's Λ = 0.43, F (3, 60) = 26.88, $p < .001$), as well as a main effect of picture category, with injury pictures rated as more negative, arousing, and disgusting as neutral pictures (Λ = 0.25, F (3, 60) =60.72, $p < .001$). Crucially, there was an interaction effect of group and picture category, such that BII-fearful participants rated injury pictures as more negative, arousing, and disgusting than control participants did (Λ = 0.50, F (3, 60) = 19.86, $p < .001$), while the two groups gave similar ratings for neutral pictures.

Data treatment and statistical methods. Practice blocks were not analyzed. Trials were eliminated if response times were shorter than 100 ms or longer than 1000 ms (1.92% of trials), and if, incidentally, prime and target consisted of the exact same image (1.25% of trials). Repeated-measure analyzes of variance (ANOVAs) were performed with Greenhouse-Geisser-corrected p values. Analyzes of response times are restricted to trials on which participants made correct responses. Additionally, we report error rates. Error rates were arc sine transformed to make them compatible with ANOVA requirements. We report F values with subscripts indicating the respective effect (e.g., F_{cxS} for the interaction of consistency and SOA).

4.3. Results

We first analyze the *influence of the primes on response times* in the two groups and link the effect to *the influence of the target on overall response times.* Second, we test whether the influences of primes and targets are also apparent in the fastest responses (i.e, in the 2nd and 3rd deciles).

4.3.1. Influence of the primes on priming effects

Influence of the primes on response times. Response times for the two groups (*controls* and *BII fear*) and targets (*injuries* vs. *unharmed body parts*) are displayed in Figure 15. We conducted an ANOVA with factors of group *(G),* prime (*P*), consistency (*C*), and SOA *(S)*. In all four panels, consistent trials (where prime and target belonged to the same response category) produced faster responses than inconsistent trials (*controls*: $F_C(1,22) = 81.61$, $p < .001$, for error rates: $F_C(1,22) = 26.03$, $p < .001$; *BII fear*: $F_C(1,18) = 88.64$, $p < .001$, for error rates: $F_C(1,18) = 20.81$, $p < .001$). This *priming effect* increased with increasing SOA (*controls*: $F_{CxS}(3,66) = 10.48$, $p < .001$, for error rates: $F_C(3,66) = 4.55$, $p = .008$; *BII fear*: $F_{CxS}(3,54) = 29.66$, $p < .001$, for error rates: $F_C(3,54) = 9.91$, $p < .001$).

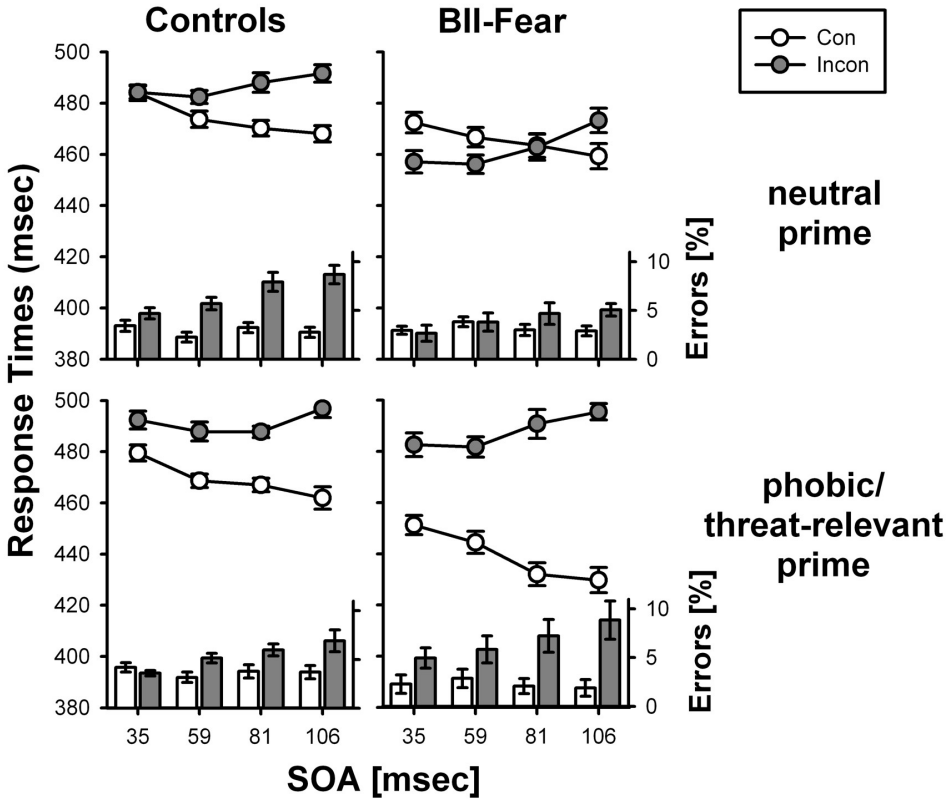

Fig. 15. Priming effects in response times and error rates for each group, separately for the two different prime types.

Priming effects for the two primes differed between the two groups ($F_{GxPxC}(1,40) = 7.92$, $p = .008$), also by trend in error rates: $F_{GxPxC}(1,40) = 3.87$, $p = .056$ (Fig. 15). As expected, injury primes elicited the largest priming effect in the BII-fearful group. We further separated priming effects for neutral and threat-relevant primes and analyzed whether the priming effects differed between the two groups. The two groups differed significantly for phobic/threat-relevant primes ($F_{GxC}(1,40) = 17.14$, $p < .001$; for error rates: $F_{GxC}(1,40) = 2.03$, $p = .162$) and showed a difference by trend for the neutral primes ($F_{GxC}(1,40) = 4.05$, $p = .051$; for error rates: $F_{GxC}(1,40) = 3.94$, $p = .054$). In other words, injury primes clearly augment the priming effect measured in response times compared to the neutral primes. Note that the observed priming effects strongly depend on *the influence of the target on overall response times* (Fig. 16). We analyzed the results within each group conducting an ANOVA with factors of group *(G)* and target (*T*). We hypothesized that in BII-fearful participants pictures of small injuries should be

processed more rapidly. Correspondingly, BII-fearful participants responded faster to phobic pictures of injuries than to neutral targets (F_T (1,18) = 11.75, p = .002); on average, these responses were about 23.26 ms faster. In the non-anxious control group, targets had no main effect (F_T (1,22) = 1.64, p = .213). However, in this group error rates were higher in trials where threat-relevant targets of small injuries appeared (F_T (1,18) = 5.58, p = .027). In contrast, BII-fearful participants were more accurate when phobic targets were presented (Fig. 16, lower panel). This rules out that the advantage in processing speed for phobic targets in that group is due to a speed-accuracy tradeoff.

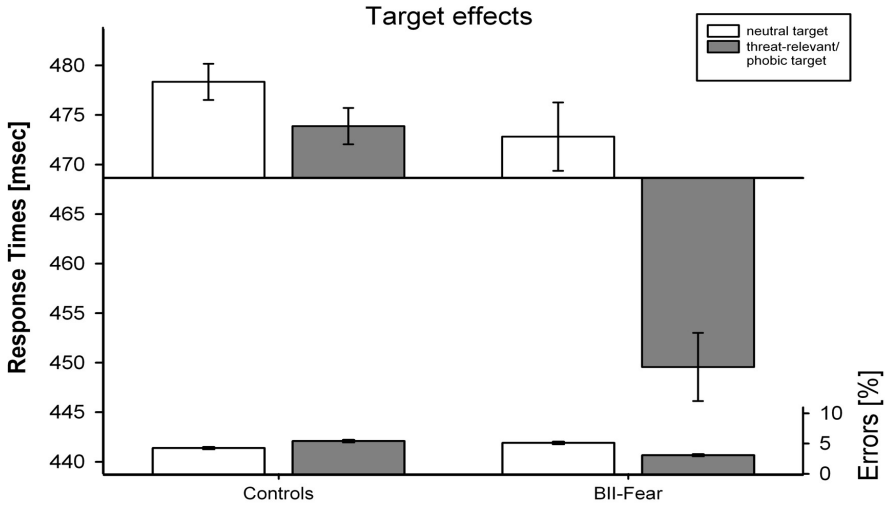

Fig. 16. Upper panel: Response times to different target types averaged for each group, shown relative to the grand average response time. Lower panel: Error rates (in percentage) are displayed. In both plots, different gray scales indicate different target types.

4.3.2. Results of 2nd and 3rd deciles

The analysis of the results in the 2nd and 3rd deciles enables us to draw conclusions about the underlying physiological mechanisms of information processing. Additionally, we analyzed deciles 2 to 9 to investigate whether the magnitude of response priming effect changes over the course of the response time distribution. The 1st and 10th deciles are not well suited for such an analysis because they are too dependent on possible outliers. The deciles are obtained by sorting raw response times,

separately for each participant and condition (defined by the levels of consistency, SOA, and either by prime or target). Note that response times shorter than 100 ms and longer than 1000ms were not excluded. Subsequently, we calculated mean response times for 10 %-bins ranging from 0 to 100 %.

We analyzed the response times of the 2nd and 3rd deciles by performing an ANOVA with factors of group *(G)* and target (*T*). Indeed, the specific effect of phobic targets on overall response times was already observable in the fastest responses ($F_{GxT}(1,40) = 10.10$, $p = .003$; Fig. 17A). We conducted also an ANOVA with factors of group *(G),* prime (*P*), consistency (*C*), and SOA *(S)* and as in the overall data, priming effects were larger for the phobic primes in the BII-fearful group ($F_{GxC}(1,40) = 8.94$, $p = .005$; Fig. 17B). This indicates that effects outlined above were already present in the fastest responses and the processing advantage might well rely on the first sweep of neuronal activation running through the visuomotor system (cf. Schmidt, Haberkamp, Veltkamp et al., 2011).

Additionally, we conducted an ANOVA with factors of group *(G),* prime (*P*), consistency (*C*), SOA *(S)* and decile (D). The analysis revealed neither an interaction of factors consistency and decile nor of consistency, SOA, and decile ($F_{CxD}(7,280) = 0.99$, $p = .345$; $F_{CxDxS}(21,840) = 0.33$, $p = .706$) nor of an interaction with these factors and the factor group ($F_{CxDxG}(7,280) = 0.06$, $p = .872$; $F_{CxDxSxG}(21,840) = 1.18$, $p = .311$). The results indicate that response priming effects are already fully developed in the 2nd and 3rd deciles and do not increase or decrease in the subsequent deciles.

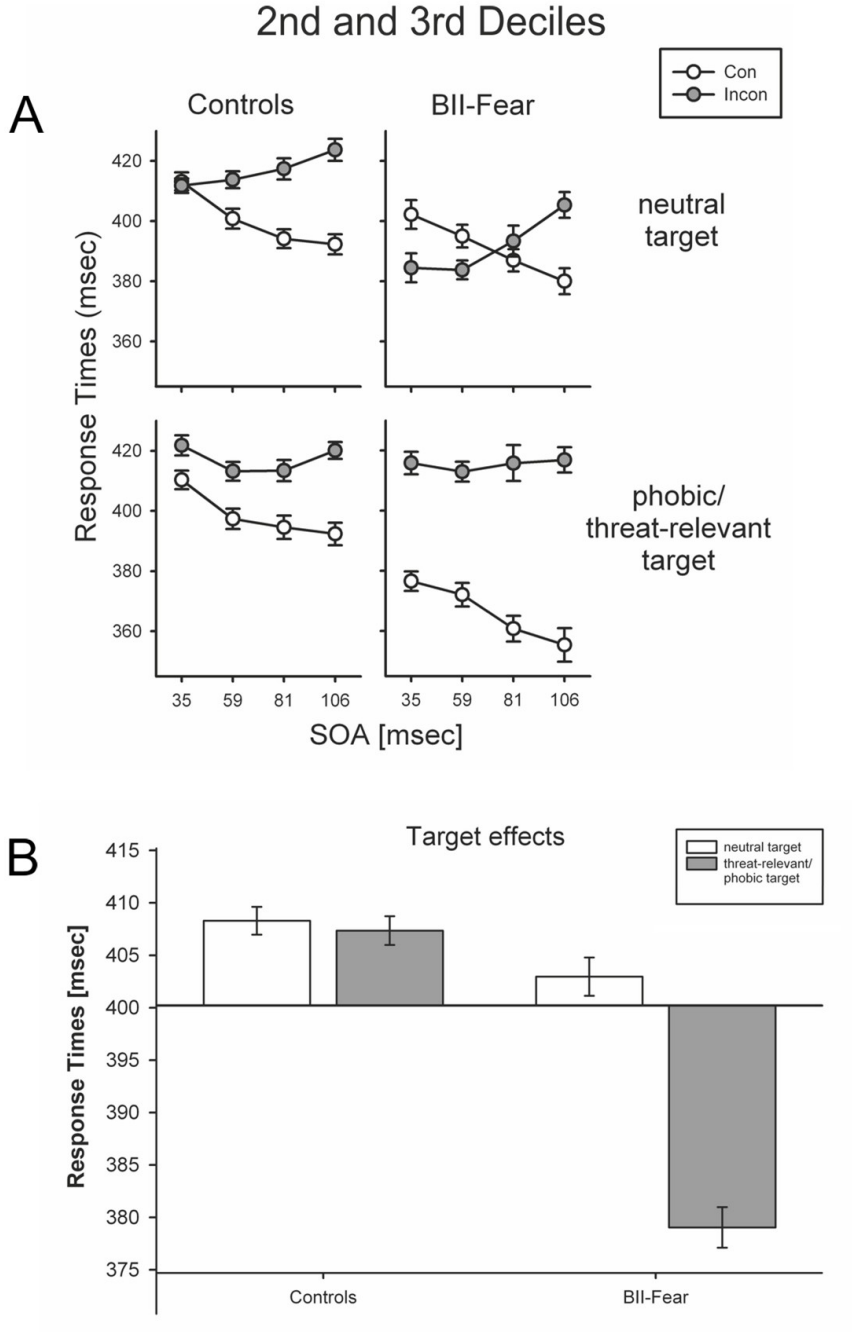

Fig. 17. (A) Response times for each group, separately for the two different prime types in the 2nd and 3rd deciles. (B) Response times to the two targets for the two groups, shown relative to the grand average response time for 2nd and 3rd deciles of the response time distribution.

4.4. Discussion

Overall, we found robust response priming effects for each of the two prime categories in the two groups of non-anxious control and BII-fearful individuals. In all experimental conditions (except one), inconsistent trials led to slower response times and more errors compared to consistent ones. These findings are in line with previous results from the image categorization literature (e.g., Bacon-Macé et al., 2007; Kirchner & Thorpe, 2006) as well as the response priming study with natural images (Schmidt & Schmidt, 2009), that show that natural image categories are able to rapidly activate motor responses assigned to them (for a review see Fabre-Thorpe, 2011). More specifically, we were interested in systematic differences between response patterns in the two groups. We expected such differences in the magnitude of priming effects (reflecting processing aspects of the prime) as well as in the overall response times (reflecting processing aspects of the target).

In the group of control participants, all primes produced strong and reliable priming effects depending on their consistency with the targets. However, priming effects from threat-relevant and neutral primes did not differ. Additionally, we found no systematic influence of threat-relevant and neutral targets on overall response times. Thus, we found no advantage for threat-relevant stimuli of small injuries in non-anxious control participants. Also, no advantage occurred in the fastest responses (2^{nd} and 3^{rd} deciles). These findings are in line with the image ratings, in which non-anxious controls rated the injury pictures as only slightly negative, arousing, or disgusting, compared to their ratings of the neutral pictures of unharmed body parts (Table 4). Obviously, the mild unpleasantness of the images had no discernible influence on response times.

In contrast, in BII-fearful participants, phobic primes elicited larger priming effects in the BII-fearful group compared to neutral primes and in comparison to the control group. As expected, they responded faster to injury targets than to neutral targets, indicating a visuomotor processing advantage for phobic images similar to that observed in animal phobias (e.g., Mogg & Bradley, 2006; Öhman, Flykt et al., 2001; Rinck & Becker, 2006; also cf. Experiment 1, Chapter 2). Additionally, they responded faster to injury targets compared to the control group. Most interestingly, all observed effects are already present in the fastest responses (deciles 2 and 3). These findings

support the notion that responses of the two groups were based on the first feedforward sweep of neuronal activation proceeding through the visuomotor system. In the group of BII-fearful participants, fastest responses are even further accelerated by phobic targets. These results suggest that BII-fearful participants process phobic images principally different compared to the non-anxious group.

We believe that this enhancement in BII-fearful participants might base on long-term perceptual learning processes (cf. Discussion of Experiment 1, Section 2.4.1.). Because perceptual learning modulates the processing hardware concerned with a specific stimulus class, the processing advantage encompasses the first feedforward sweep of visual processing. Even complex stimuli with a variety of different features such as natural images of injuries can be processed rapidly and automatically. We embed our findings within a feedforward theory of response priming, suggesting that enhanced information processing is based on sequential feedforward sweeps elicited by prime and target stimuli which activate the associated motor responses in strict sequence and without temporal overlap (*rapid-chase theory;* cf. Section 1.4.2.). Indeed, in the present data all modulatory effects of phobic material on response times and priming effects were fully present in the fastest responses, that is, in the 2nd and 3rd deciles of the response time distribution, consistent with such a simple feedforward model.

Our findings are in contrast to those earlier studies that reported no processing enhancement for BII phobic material in BII-fearful individuals (cf. Sawchuk et al., 1999; Buodo et al., 2006, 2007; Wenzel & Holt, 1999). We assume this to be in part a consequence of the different methodological approaches (i.e., response priming paradigms compared to other paradigms are highly sensitive for measuring early and automatic visuomotor information processing), and the different selection of stimulus material.

We did not use highly arousing images of severe mutilations in our study but pictures of minor injuries. By that, we ensured that the two groups of BII-fearful and control participants were sufficiently different in their ratings of the stimulus material. In other words, images of severe injuries or mutilated bodies that were used in earlier studies may have also evoked strong reactions in non-anxious controls and thereby abolished possible differences between them and phobic participants. Thus, we believe that using pictures of just small injuries is crucial when investigating response

differences between non-anxious control and fearful participants. In that context, Lissek, Pine, and Grillon (2006) refer to the psychological concept of the *strong situation* (Ickes, 1982; Mischel, 1977; Monson & Snyder, 1977) in which unambiguous stimuli yield uniform reactions and expectancies. On the contrary, they refer to the *weak situation* in which stimuli are less-defined and of lower salience. The authors argue that weak situations diminish the situational influence and strengthen the influence of the individual participant. Therefore, using weak stimulus material might facilitate the differences between non-anxious and fearful groups. We are convinced that the use of less severe stimulus material should also be considered in future studies on phobias.

Additionally, we matched the pictures of injuries and unharmed body, such that an equivalent number of injured and unharmed body part pictures (e.g., hands, legs) were presented. Matching the pictures makes between group comparisons more reliable because neutral and threat-relevant/phobic pictures do not differ in picture content. To the best of our knowledge, this was not done in previous studies with BII-fearful participants. The stimulus material applied in this study might have contributed to the differences in information processing observed between the non-anxious and BII-fearful group, while other studies did not find such effects (cf. Sawchuk et al., 1999; Buodo et al., 2006, 2007; Wenzel & Holt, 1999).

Note that control and threat-relevant stimuli differed in their appearance. Because threat-relevant stimuli were pictures of small injuries, the proportion of the color *red* is higher in these images. As a result, responses to these pictures might be faster because of the higher salience. Still, we decided to present colored pictures because red blood is an important characteristic of the threat-relevant injury pictures and probably play an important role in inducing fear in BII-fearful individuals. However, the non-anxious group controls for a potential influence of stimulus characteristics on the responses. In this group, response times were not different between neutral and threat-relevant images; indicating that stimulus characteristics alone do not lead to enhanced information processing.

Although, we found evidence for enhanced information processing, the current study has limitations which should be considered. A limitation of our study is the fact that we did not use threat-relevant (but non-phobic) pictures. In the eye-tracking study

by Armstrong and colleagues (2013), BII-fearful participants attended to pictures of injections most frequently. Though, the authors found no difference between the percentage of the initial fixations of the BII-fearful participants on phobic and merely threat-relevant pictures (e.g., attacking dogs). This suggests that BII-fearful participants might be better in detecting phobic stimuli comparable to other specific phobias; but, that this bias might also apply to other stimuli with negative valence. Thus, we can not exclude that the reported effects are based on a general hypervigilance of BII-fearful participants and not to a specific reaction towards the phobic stimuli. However, note that for instance Tolin and colleagues (1999) reported that BII-fearful participants avoided pictures of injections but not threat-relevant pictures of spiders (also cf. Buodo et al., 2010).

In summary, our results show that phobic stimuli are processed faster by BII-fearful participants as revealed by response time differences. Our results are in line with more recent studies (Buodo et al., 2010; Sarlo et al., 2011) which suggest a preferential processing of phobic stimuli by BII-fearful participants. This accelerated information processing of phobic images was comparable to those reported in spider-fearful participants classifying phobic vs. threat-relevant vs. neutral stimuli as reported in Experiment 1 (Chapter 2). Importantly, this suggests that despite the distinct clinical phenomenology of BII phobia, the basic visuomotor information processes are similar to those in other specific phobias.

5. Experiment 4 - Spiders capture attention: A prior-entry-effect for phobia-relevant stimuli

5.1. Introduction

Attention can be modulated in two different ways: in a top-down manner (i.e., through behavioral goals, that means by a specific search task; e.g., search for the red dot) or in a bottom-up manner (i.e., through the characteristics of the stimulus; e.g., the color of a dot; Yantis, 2000). One stimulus characteristic that modulates attention is its saliency (e.g., Pashler, 1988; Theeuwes, 1992, for reviews see Corbetta & Shulman, 2002; Theeuwes, 2010). For example, a red circle embedded in an array of green circles is very salient, and, thus, may automatically capture attention. Saliency might not depend on perceptual characteristics alone, but attention might also be modulated by the emotional significance of a stimulus. In this context, it would be highly reasonable that a perilous animal that hides in the woods is automatically attended (cf. Mathews & Mackintosh, 1998). Indeed, it was shown that threat-relevant stimuli (e.g., spiders or threatening faces) are more likely to capture attention than neutral stimuli (e.g., Eastwood et al., 2001; Fox et al., 2000; Koster et al., 2004, but see Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; also cf. Section 1.5. "Attentional biases in specific phobias").

One way to measure attentional capture is to use Temporal Order Judgments (TOJs; cf. Section 1.5.1 "The prior entry paradigm"). West and colleagues (2009) demonstrated by applying TOJs that angry faces capture attention compared to neutral faces, and that these stimuli show a visual prior entry effect (also cf. Fecica & Stolz, 2008). Note that likewise some evidence suggest spiders should be able to capture attention (Mogg & Bradley, 2006; Rinck & Becker, 2006; for reviews on attentional biases in general see Mathews & MacLeod, 2005; Bar-Haim et al., 2007).[15] In contrast

[15] For example, Mogg and Bradley (2006) demonstrated in a dot probe task that spider-fearful participants attended to spider pictures within the first 200 ms and that their response times decreased in trials where the dot was presented at the position of the spider picture. Furthermore, Rinck and Becker (2006) demonstrated in an eye tracking study that the very first fixation of spider-fearful participants was more often on the spider pictures compared to the non-anxious control participants whose first fixation was equally often on the spider or the neutral control pictures.

to traditional studies on prior entry in which attention is typically manipulated, West and colleagues (2009) did not cue the stimuli that were used but rather assumed that threatening faces would automatically capture attention in a bottom-up manner due to the emotional significance of the threatening face stimuli. However, these results cannot be generalized because faces are processed differently compared to objects or animals. More specifically, faces are processed in a holistic fashion by specific cortical regions (the fusiform face area; cf. McKone, Kanwisher, & Duchaine, 2006; Kanwisher, 2010). Additionally, no other study I know of demonstrated a visual prior entry effect with a different type of threat-relevant or phobic stimuli. Therefore, we wanted to know whether the same effect can also be found in spider-fearful participants for spider pictures or whether the prior entry effect demonstrated by West and colleagues (2009) is restricted to face stimuli.

Comparable to the study of West and colleagues (2009), we aimed to test if the attentional bias for spiders reported above is strong enough to elicit a visual prior entry effect in the group of spider-fearful participants. In our study, two groups of participants took part; one group of spider-fearful and one group of non-anxious control participants. The stimuli comprised of three categories of natural images of animals (spiders, snakes, and butterflies). In the present study, spiders represent *phobic* stimuli for the group of spider-fearful participants, but they are merely *fear-relevant* for the group of non-anxious controls. Snakes represent *fear-relevant* and butterflies *neutral* control stimuli for both groups. Also, there was a neutral category of natural images of non-animals (mushrooms and flowers).

We decided to use natural images in the current study due to their high ecological validity. In each trial, one animal picture and one non-animal picture were presented with a varied SOA (0 ms, 12 ms, 24 ms, 35 ms, or 47 ms; Fig. 18). We did not cue the stimuli but assumed that spider pictures would automatically capture attention of spider-fearful participants (cf. West et al., 2009).

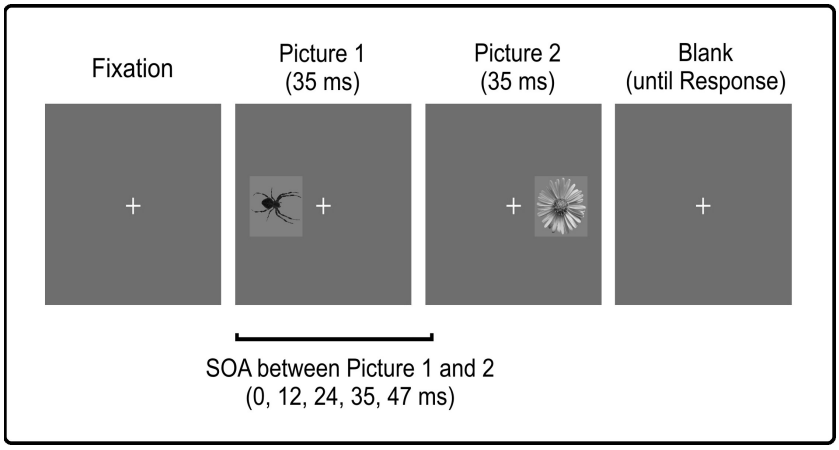

Fig. 18. Stimuli and Procedure. Picture 1 and picture 2 were presented at varied SOAs in the sequence displayed. The participants' task was to indicate which of the pictures was presented first.

The experimental setup described above allows us to investigate three questions: (1) whether spider-fearful individuals process phobic images of spiders faster than fear-relevant animals (snakes) or neutral animals (butterflies)? (2) Whether spider-fearful participants process the presented pictures of spiders faster than non-anxious controls? (3) Whether non-anxious controls process fear-relevant stimuli (spiders, snakes) faster than neutral stimuli?

In Experiment 1 (Chapter 2), we found enhanced information processing for phobic pictures in spider-fearful but not for fear-relevant pictures in non-anxious control participants using the same stimulus material (also cf. Tipples et al., 2002). Therefore, we expect that no visual prior entry effects for fear-relevant spiders and snakes compared to the neutral category of butterflies will occur in the group of non-anxious control participants. However, we expect to find a visual prior entry effect for phobic spiders in spider-fearful participants (within-group-prior-entry effect). Furthermore, we expect to find a prior entry effect for spiders in the spider-fearful group compared to the non-anxious control group (between-groups-prior-entry effect).

5.2. Methods

Participants. Twenty-eight participants recruited through the University of Kaiserslautern took part in the study. All of them were naïve to the purpose of the study. Fourteen of them reported that they were highly afraid of spiders but not of snakes (8 women and 6 men; age range, mean = 25.75, SEM = 2.45). 14 participants reported being afraid of neither spiders nor snakes (11 women, 3 men; age range, mean = 24.50, SEM = 1.08). All participants were screened for fear of spiders or snakes before the experiment started (Fig. 19). For this purpose, two spider questionnaires and one snake questionnaire were applied (German version of the "Spider Questionnaire" SPQ; Hamm, 2006; original version by Klorman et al., 1974; German questionnaire "Fragebogen zur Angst vor Spinnen [Fear of spiders questionnaire]" FAS; Rinck et al., 2002; German version of the "Snake Questionnaire" SNAQ; Hamm, 2006; original version by Klorman et al., 1974).

To ensure that the two groups differed substantially, non-anxious control participants had to score below the 25th percentile in the SPQ and spider-fearful participants had to score above the 75th percentile in the SPQ. All participants had to score below the 50th percentile in the SNAQ to exclude persons with snake phobia from the study. For the FAS, only guideline values exits. However, the two groups also differed significantly in this questionnaire ($T(14.49) = 11.68$, $p < .001$; Fig. 19).

Three additional participants who reported being highly afraid of spiders and two participants who reported being afraid of neither spiders or snakes were excluded after the diagnostic session due to high scores in the snake questionnaire. One participant who reported being highly afraid of spiders was excluded due to low scores in the two spider questionnaires. These participants were not included in the number of participants stated above.

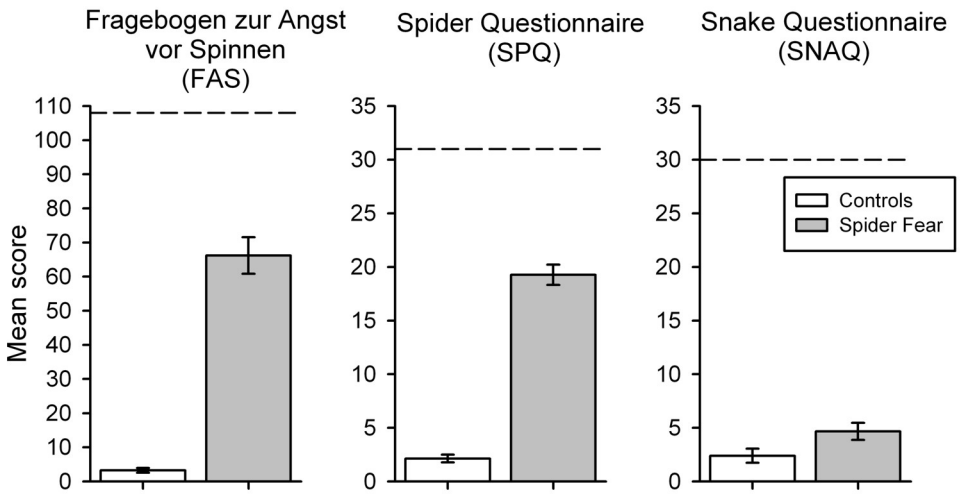

Fig. 19. Results of two spider and one snake questionnaire (German version of the "Spider Questionnaire" SPQ; Hamm, 2006; German questionnaire "Fragebogen zur Angst vor Spinnen" FAS; Rinck et al., 2002; German version of the "Snake Questionnaire" SNAQ; Hamm, 2006) separately for two different groups (non-anxious controls, spider-fearful participants). Dashed lines indicate the maximum score obtainable in the respective questionnaire.

In addition, all spider-fearful participants were tested for specific anxiety disorders using a structured diagnostic interview ("Diagnostic Interview for Psychological Symptoms (DIPS)"; Schneider & Margraf, 2006), based on the DSM-IV-TR (APA, 2000). All fearful participants except one met at least four criteria for specific phobia. 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 participants in the experimental groups as "fearful" instead of "phobic".

All participants completed the Beck Depression Inventory (BDI; Beck et al., 1961; mean = 4.00, SEM = 0.74). Three of the participants (two spider-fearful, one control) were excluded for high depression scores above 10, which indicate the existence of a mild depressions (cf. Experiment 1/Chapter 2). These participants are also already subtracted from the number of participants reported above.

Participants had normal or corrected-to-normal visual acuity and received payment of € 6 per hour. All of them gave informed consent and were treated in accordance with the ethical guidelines of the American Psychological Association.

Apparatus. The participants were seated in a dimly lit room in front of a color cathode-ray monitor (1280x1024 pixels, retrace rate 85 Hz) at a viewing distance of approximately 70 cm.

Stimuli and procedure. Five different types of gray scale images (spiders, snakes, butterflies, mushrooms, and flowers), each containing thirty different pictures, were presented against a lighter gray background (8.75 cd/m^2). Each trial started with the appearance of the central fixation point (Fig. 18). After a varying delay, the first picture was displayed for 35 ms either to the left or the right of the fixation point at 3.74°. The second one was shown for 35 ms at the opposite position of the fixation point, i.e. to the left or right of the fixation point, respectively, at SOAs of 0 ms, 12 ms, 24 ms, 35 ms, or 47 ms. Both pictures were presented at a visual angle of 4.16° (1 mm ≈ 0.008° of visual angle). In each trial, animals (spiders, snakes, or butterflies) and neutral non-animals (flowers and mushrooms) were presented in pairs. That results in three possible conditions: "spider vs. neutral picture", "snake vs. neutral picture", and "butterfly vs. neutral picture". In each block, only one type of animal picture was combined with the neutral non-animal pictures. Blocks were presented in a pseudo-random order. In each session, 27 blocks – consisting of 32 trials – were presented. Both non-animal picture types occurred in every block. In order to avoid a response bias towards spiders, the participants' task was to indicate whether the animal (and not the specific animal, e.g., spider) or the non-animal picture came first.

Although one can theoretically assume that for stimuli in the same sensory modality the PSS would coincide with physical simultaneity (SOA 0) if attention is not manipulated, several studies revealed at least small deviations of the PSS from physical simultaneity (e.g., vision: Shore, Spence & Klein, 2001; tactile modality: Yates & Nicholls, 2011). These findings are probably due to the influence of low-level feature differences between the stimuli on temporal perception. Thus, computing a prior entry effect between a control ("butterfly vs. neutral picture") and experimental condition ("spider vs. neutral picture", "snake vs. neutral picture") corrects for possible effects of low-level feature differences which could lead either to over- or underestimation of prior entry. Participants received visual feedback on the correctness of their responses after each block. Each participant performed two 1.5-hour sessions. The first session started with the diagnostic screening which was followed by a 1-hour computer

experiment. The second session started with a second 1-hour computer experiment and was followed by a picture evaluation of the images presented during the experiment.

The picture rating after the second session involved three dimensions (valence, arousal, and disgust). All dimensions were rated on a six-point rating scale. Scales were coded so that high scores reflected high arousal and disgust, respectively. Positive scores in the valence ratings represent positive emotions towards the image, a score of zero means that neither positive nor negative emotions are involved, and negative scores reflect negative emotions (Table 5). All three scores were submitted as dependent variables to a multivariate analysis of variance with factors of group and picture type. In the image rating, the groups (non-anxious control and spider-fearful participants) differed significantly regarding their evaluations. A main effect of group (Wilk's λ = 0.51, $F(3,128) = 41.62$, $p < .001$) and picture type (Wilk's $\lambda = 0.15$, $F(12,338.95) = 29.99$, $p < .001$), as well as an interaction effect of group and picture type was observed (Wilk's $\lambda = 0.26$, $F(12,338.95) = 18.73$, $p < .001$), reflecting the fact that spider-fearful participants rated the spider images more negatively on all three dimensions as compared to neutral images or non-anxious participants. Participants were debriefed after the second session and received an explanation of the purpose of the study.

Table 5: Participants' mean scores (with standard deviations) for image evaluation separately for scale (valence, arousal, and disgust) for each picture type and each group. Bold letters indicate phobic image categories.

	Spider Fear	Controls
Image rating		
Spider - Valence	**-2.40 (0.85)**	-0.22 (1.04)
Snake - Valence	-0.18 (0.72)	-0.36 (1.06)
Butterfly - Valence	0.37 (0.81)	1.21 (1.08)
Mushroom - Valence	0.11 (0.53)	0.10 (0.80)
Flower - Valence	0.80 (0.93)	0.99 (1.19)
Spider - Arousal	**4.43 (1.49)**	1.06 (1.60)
Snake - Arousal	0.39 (0.71)	0.80 (1.39)
Butterfly - Arousal	0.10 (0.33)	0.92 (1.61)
Mushroom - Arousal	0.17 (0.63)	0.65 (1.06)
Flower - Arousal	0.18 (0.56)	0.64 (1.19)
Spider - Disgust	**4.94 (1.33)**	0.75 (0.98)
Snake - Disgust	0.38 (0.66)	0.19 (0.52)
Butterfly - Disgust	0.08 (0.32)	0.09 (0.34)
Mushroom - Disgust	0.27 (0.87)	0.28 (0.84)
Flower - Disgust	0.01 (0.05)	0.03 (0.18)

Note: Ratings on 6-point Likert scale (for valence ratings: -3 = „extremely unpleasant", 3 = "extremely pleasant"; for all other ratings 0 = "not at all", 6 = "extremely").

Data treatment and statistical methods. Practice blocks were not analyzed. Univariate analyzes of variance (ANOVAs) were performed with Greenhouse-Geisser-corrected p values. We report F values with subscripts indicating the respective effect (e.g., F_{GxC} for the interaction of group and picture condition). Additionally, we estimated the *slope* and the *shift* in the psychophysical functions of each participant for the three experimental conditions ("spider picture vs. neutral picture", "snake picture vs. neutral picture", "butterfly picture vs. neutral picture") by non-linear regression based on Birnbaum's (1968) logistic model (Suen, 1990):

$$\frac{1}{1+e^{(-1.7*slope*(SOA-shift))}}$$

We extracted the parameters *slope* and *shift* and tested them with independent two-sample *t*-tests. Additionally, we report the effect size using Cohen's *d* for all independent two-sample *t*-tests (Cohen, 1988).[16]

5.3. Results

Firstly, we performed a univariate analysis of variance (ANOVA) with factors of group *(G;* non-anxious controls vs. spider-fearful participants*)*, picture condition *(PC;* "spider vs. neutral picture", "snake vs. neutral picture", "butterfly vs. neutral picture"), and SOA (*S*; -47 ms, -35 ms, -24 ms, -12 ms, 0 ms, 12 ms, 24 ms, 35 ms, or 47 ms). The interaction of group and picture condition was significant ($F_{GXPC}(2, 702) = 8.02$, $p < .001$) confirming that the two groups differed in their rating concerning the picture condition. As expected, a main effect of SOA ($F_S(2, 702) = 8.02$, $p < .001$) occurred, confirming that the ratings depend on the respective SOA. This is not surprising given that SOA and picture presentation are related (i.e., negative SOAs indicate that animal pictures were presented first, positive SOAs indicate that neutral pictures were presented first; Fig. 20, 21).

We also analyzed the differences between the two groups for the two parameters slope and shift using independent two-sample *t*-tests (Fig. 20). Results show that the two groups do not differ in the slope of their function in any condition ("spider vs. neutral picture", "snake vs. neutral picture", "butterfly vs. neutral picture": all $|t(26)| \leq 0.57$, $p > .05$, $.14 \leq d < .23$). Most importantly, significant differences between the groups appear in the shift of the fitted curves in the "spider vs. neutral picture" condition ($t(26) = -2.23$, $p = .034$, $d = .65$). No group differences in the "snake vs. neutral picture" condition appear ($t(26) = 0.99$, $p > .05$, $d = .43$). As expected, the analysis reveals no group differences in the control condition ("butterfly vs. neutral picture", $t(26) = 0.83$, $p > .05$, $d = .31$). The differences in PSS between the groups add up to 6.87 ms in the "spider vs. neutral picture", up to 1.89 ms in the "snake vs. neutral picture", and up to 1.56 ms in the "butterfly vs. neutral picture" condition.[17]

[16] Note that effect sizes of $d = .2$ are considered as being small, of $d = .5$ as being medium, and of $d = .8$ as being large (Cohen, 1988).

[17] Note that the calculation of the PSSs is based on the shift of Birnbaum's logistic model (1968).

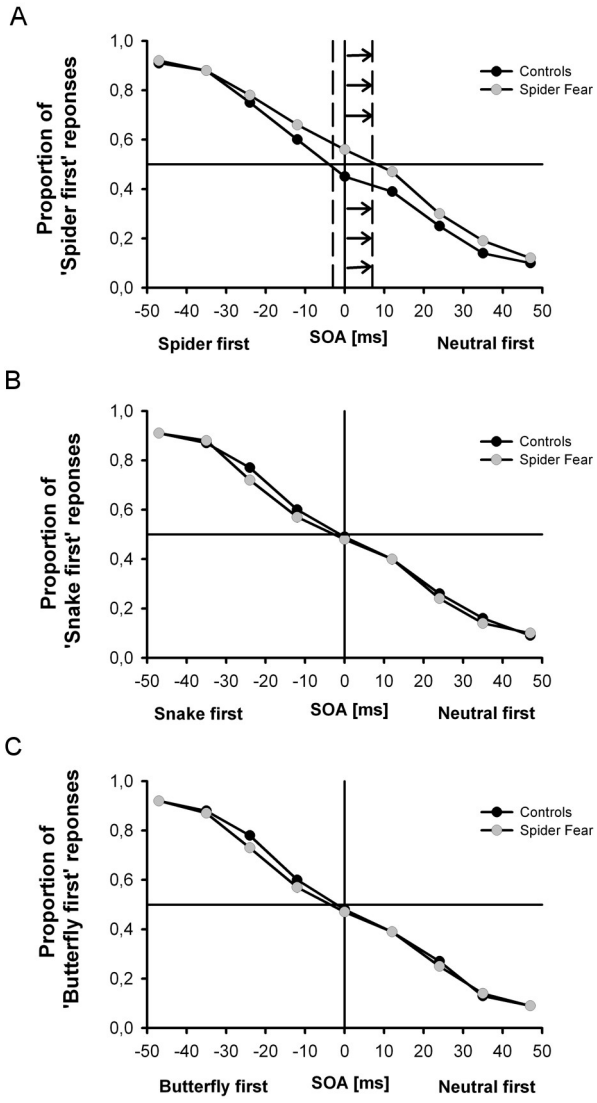

Fig. 20. Three panels – one for each animal condition (A: "spider vs. neutral picture", B: "snake vs. neutral picture", C: "butterfly vs. neutral picture") – are displayed. In each panel, proportion of 'animal first' responses are plotted. Results of the two groups are indicated by the two different lines. Arrows indicate the prior entry effect in panel A.

Finally, we conducted a multivariate ANOVA to analyze whether a difference between the conditions in the shift and/or slope exist within each group (Fig. 21). We found no significant difference in the control group neither for the slope nor for the shift of the psychometric functions (shift: $F(2,26) = 1.15$, $p = .329$; slope: $F(2,26) = 0.20$, $p = .730$). Additionally, we found no differences in the slope of the functions in the spider-fearful group ($F(2,26) = 0.16$, $p = .814$). However, as expected, we found a significant

difference in the shift between the conditions within the group of spider-fearful participants of approximately 7 ms ($F(2,26) = 4.55$, $p = .046$). This finding confirms that spiders elicit a prior entry effect in the experimental group.

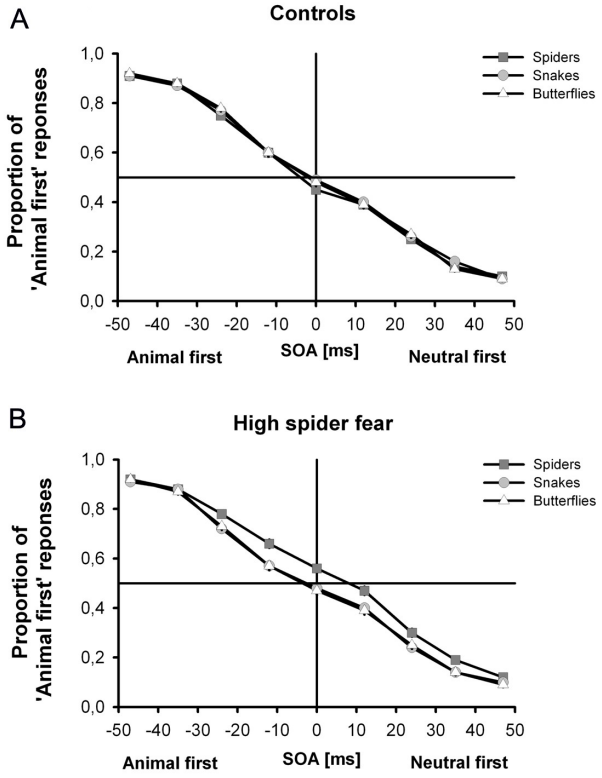

Fig. 21. Responses are plotted for the two different groups (A: non-anxious controls, B: Spider fear). Each line indicates one animal condition ("spider vs. neutral picture", "snake vs. neutral picture", "butterfly vs. neutral picture"). Note that the plots here and in all remaining figures are based on the row data. Therefore, the differences between the plotted lines can differ from the fitted functions of Birnbaum's logistic model (1968).

5.4. Discussion

The purpose of the present study was to investigate if the attentional bias towards spiders - which recent studies (e.g., Mogg & Bradley, 2006; Rinck & Becker, 2006) evidenced in individuals with spider phobia – is strong enough to trigger a prior entry effect. Theoretically there are two possibilities in which such a prior entry effect

could be revealed: First, between groups - that means spider-fearful participants process spiders faster than non-anxious control participants - and secondly, within groups - that means spider-fearful individuals should process spiders faster compared to neutral material of butterflies. Most importantly, we found a between-group-prior-entry effect for spiders of 6.5 ms. Thus, the spider-fearful participants processed spider 6.5 ms faster compared to non-anxious control participants. The prior entry effect between the two groups has a comparable magnitude as the prior entry effect elicited by threatening faces in the study by West and colleagues (2009). In their study, the authors reported prior entry effects from 5.88 to 7.85 ms for pictures of schematic faces and one exceptional large prior entry effects of 18.26 ms for pictures of real faces.

Furthermore, we found an approximately 7 ms within-group-prior-entry-effect in spider-fearful participants but no prior entry effect for spiders in the non-anxious control group. We assume that this effect in the spider-fearful group is based on the different emotional valence of the spider pictures compared to the neutral pictures of mushrooms and flowers. Accordingly, spiders were rated as highly negative by the experimental group.

As expected, we found no prior entry effect for threat-relevant images (spiders and snakes) in the non-anxious control group confirm earlier findings using the same stimulus material. In this study, non-anxious controls also showed no enhanced information processing of threat-relevant pictures. These results are in contrast to studies which demonstrated attentional biases as well as advantages in information processing of threat-relevant pictures in the non-anxious population (cf. Fox et al., 2000; Van Damme, Gallace, Spence, Crombez, & Moseley, 2009; but see Tipples et al., 2002).

We assume that the stimulus material applied in our study (i.e., pictures of spiders and snakes) was insufficiently threatening for non-anxious control participants to capture attention. This assumption is supported by the picture ratings of the non-anxious group. Overall, they rated the fear-relevant pictures of spiders and snakes as neutral on the valence scale, only slightly arousing, and only slightly disgusting (cf. Table 5). However, West and colleagues (2009) reported visual prior entry effects in their sample of non-anxious participants for threatening faces. We assume that this might be due to the fact that the authors did not use a control condition in their

experiments (i.e., in their study prior entry effects were calculated as PSS-deviation from zero). Thus, their prior entry effects were not corrected for possible non-emotional influences; for example, differences in low-level features between the target stimuli. However, such low-level feature differences could lead to non-zero PSS-values also in control conditions (cf. Shore, Spence & Klein, 2001; Yates & Nicholls, 2011). Thus, calculating a prior entry effect as PSS-deviation from zero could under- or overestimate the real size of prior entry. Our results as well as the results by Schettino and colleagues (2013) using threat-relevant faces failed to replicate visual prior entry effects for merely threat-relevant stimuli in non-anxious controls participants. These findings indicate an overestimation of the size of prior entry for threatening faces.

5.4.1. Prior entry effects for snakes?

No visual prior entry effects occurred for snakes which were fear-relevant for the spider-fearful and the non-anxious-control group; neither between the spider-fearful and the control group nor within one of the groups. We hypothesized that a visual prior entry effect for snakes might occur in the spider-fearful group because we assumed that fearful participants might be more sensitive to threat-relevant stimuli per se. However, as displayed in Table 5, spider-fearful individuals rated the snake pictures as only slightly negative, arousing, and disgusting. Therefore, we assume that the threat-relevant snake pictures were not emotionally significant for either group and, therefore, did not capture attention.

5.4.2. A response bias explanation of the phobic prior entry effect?

A possible alternative explanation of our results would be that spider-fearful participants did not actually perceive spiders earlier than control participants but that they showed a response bias (e.g., Schneider & Bavelier, 2003). That means they preferentially used the response “animal first” in case the animal of the respective trial was a spider. This might seem especially possible since the animal trials where blocked (i.e., in one block only one type of animal was presented either spiders, snakes, or butterflies). An argument against this kind of response bias is that participants did not make more temporal order errors in trials in which the spider picture was present. That means the slope was not different between conditions. If spider-fearful participants would show a strong response bias for spiders, this fact should be evident in reduced

temporal discrimination accuracy due to more errors (for a refutation of the response bias argument in visual prior entry studies with attentional manipulation, see Weiß & Scharlau, 2012, and Scharlau, 2004).

In sum, we demonstrated for the first time that spider-fearful participants show a visual prior entry effect for phobic spider pictures in comparison to control participants and argue that these prior entry effects for spiders cannot be explained by a simple response bias. Furthermore, spider-fearful participants but not non-anxious control participants showed faster processing of spider pictures in comparison to threat-relevant and neutral pictures. Hence, we assume that the prior entry effects result from the attentional bias frequently reported in studies with spider-fearful individuals. We expected that the snake pictures were not emotionally significant for either group and, therefore, did not capture attention. Nevertheless, the effect sizes of the reported results are rather small and a substantial increase in sample size should be considered.

6. General discussion

Anxiety disorders are common in the German population with a 12-month prevalence of about 15 percent (Jacobi et al., 2004). Specific phobias form a major class within the class of anxiety disorders. Due to the frequent occurrences of specific phobias, an improved understanding is necessary to facilitate the classification, diagnosis, and treatment of these phobias. More specifically, one promising area is that of studying vigilance in individual with specific phobia since the early attentional bias contribute to enhanced anxiety when phobic individuals are confronted with the feared stimulus. Additionally, the early attentional bias is followed by intentional avoidance which reduces anxiety. However, this avoidance behavior shown by individuals with specific phobias contributes in turn to the maintenance of the specific phobia because it prevents sufficiently long exposure of fearful individuals to the threatening stimuli to learn that the phobic stimulus is actually harmless (Rinck & Becker, 2006).

Accordingly, I was interested to further investigate the attentional bias and the accompanied enhancement in information processing of phobic stimuli in individuals with specific phobias. Therefore, I address three research questions in the present thesis; (1) Is information processing of threatening stimuli measured by speeded responses in response priming paradigms enhanced in individuals with specific phobias? (2) Are there any differences between the different types of phobia (e.g., spider phobia vs. snake phobia)? (3) Does the frequently reported attentional bias of individuals with specific phobias also appear in temporal-order judgments? In other words, the present thesis contributes to our better understanding of specific phobias by addressing research questions which are concerned with the nature of specific phobias. Accordingly, the present experiments account for currently discussed topics in the research field of anxiety disorders and provide valuable insights into the processing of threat-relevant and phobic stimuli.

In the subsequent paragraphs, I succinctly summarize the research questions, method and most important findings of each experiment. I also aim to shed further light on two important aspects of the present thesis which were only briefly mentioned in preceding paragraphs.

First, it is frequently reported that information processing of threat-relevant or phobic stimuli is enhanced in the general population (Fox et al., 2000; Lipp & Waters,

2007; Öhman, Flykt et al., 2001; Williams et al., 2005; but see Tipples et al., 2002) as well as in individuals with specific phobias, (Lipp & Waters, 2007; Öhman, Flykt et al., 2001). However, the underlying neurophysiological mechanisms remain largely elusive. Commonly, researcher attribute improved recognition or categorization of threat-relevant stimuli to enhanced amygdala activation (e.g., Anderson & Phelps, 2001). In the following, I summarize their explanation how the amygdala contribute to the enhanced information processing of threat-relevant or phobic stimuli and discuss the plausibility of that account (Section 6.2. "Enhanced information processing and the amygdala network"). In contrast, we have argued that enhanced information processing possibly results from long-term perceptual learning rather than enhanced amygdala activation. I outline how changes in the neural hierarchy contribute to enhanced information processing efficacy (6.3. "Enhanced information processing and perceptual learning").

Second, based on our research on anxiety and emotion in the past, I have arrived at the conclusion that the emotion research field features a lot of pitfalls which can lead to misinterpretations of the emotional significance of a given stimulus. These pitfalls will be discussed in connection with the frequently reported attentional bias. Finally, I close by a summary of the most important aspects of the present thesis.

6.1. The present results

In the present thesis, we demonstrated that information processing for phobic stimuli is indeed enhanced in fearful individuals and we found discrepancies between different types of specific phobia. In Experiment 1 (Chapter 2), we investigated enhanced visuomotor processing of phobic compared to fear-relevant and neutral stimuli. Three different groups took part in the study: spider-fearful, snake-fearful, and non-anxious control participants. We used a response priming design to measure rapid and automatic motor activation by natural images (spiders, snakes, mushrooms, and flowers). We found strong priming effects in all tasks and conditions; however, results showed marked differences between groups. Most importantly, in the group of spider-fearful individuals, spider pictures had a strong and specific influence on even the fastest motor responses: Phobic primes entailed the largest priming effects, and phobic targets accelerated responses, both effects indicating speeded response activation by

phobic images. In snake-fearful participants, this processing enhancement for phobic material was less pronounced and extended to both snake and spider images. We concluded that spider phobia leads to enhanced processing capacity for phobic images.

In Experiment 3 (Chapter 4), we investigated whether information processing is also enhanced in individuals with blood-injury-injection (BII) phobia. Only few studies investigate that type of specific phobia so far, even though it has distinct features that clearly distinguish it from all other specific phobias. The present study aimed to fill that gap and explored rapid information processing of phobic stimuli (i.e., pictures of small injuries) in BII-fearful and non-anxious control participants by using a response priming paradigm. BII-fearful participants responded more rapidly to their phobic stimuli compared to neutral stimuli, whereas non-anxious control participants showed no difference in their response. Our results showed that enhanced visuomotor processing of injury pictures occurs in BII-fearful individuals. We concluded that these results are comparable to processing advantages of phobic stimuli in other specific phobias (e.g., animal phobia).

Based on the perceptual learning account (i.e., spider-fearful participants possess cells specialized in detecting spiders compared to non-anxious control participants), we hypothesized in Experiment 2 (Chapter 3) that spider-fearful participants would exhibit enhanced information processing of phobic pictures. Additionally, we assumed that they would also be better at identifying briefly presented spider primes. Two different groups took part in our study: spider-fearful and non-anxious control participants. We applied a response priming paradigm. Our stimulus material consisted of natural images (spiders, snakes, mushrooms, and flowers). A target identification task was applied to measure rapid information processing and a prime identification task to measure prime recognition. In the target identification task, we found strong priming effects in all conditions; however, in the group of spider-fearful individuals, spider pictures had a strong and specific influence on motor responses: Phobic primes entailed the largest priming effects, and phobic targets accelerated responses. Hence, we were able to replicate our findings from Experiment 1. However, in the prime identification tasks, spider-fearful participants identified all prime pictures of spiders, snakes, flowers, and mushrooms equally well. In other words, we did not find the expected improvement in spider recognition performance in the spider-fearful group. These results suggest that

classification and identification of a stimulus are based on different processing mechanisms. Stimuli can be classified during the first feedforward sweep of visuomotor processing whereas the identification of stimuli requires recurrent feedback from separate cortical areas. I conclude that perceptual learning processes might enhance information processing of phobic stimuli. However, it does not seem to facilitate identification of these stimuli.

Finally, it is widely accepted that spider phobics show an early attentional bias towards spiders. We wondered whether the internal attentional bias of spider phobics is strong enough to trigger a prior entry impression. Therefore, we used a Temporal Order Judgment (TOJ) paradigm. The paradigm is based on the assumption that attended stimuli are perceived as occurring earlier in time compared to unattended stimuli. For example, if a cued and an uncued stimulus are presented at the same time, the participant will perceive that the cued stimulus was presented first. This is known as the *Prior Entry Effect* and has been convincingly demonstrated by several recent studies of temporal perception. The prior entry effect is technically defined as the shift in the *Point of Subjective Simultaneity* (*PSS*). That means, the temporal interval at which the attended and unattended stimulus are perceived as occurring simultaneously (Spence & Parise, 2010; Weiß & Scharlau, 2011). In our final experiment of the present thesis, spider-fearful and non-anxious control participants took part. In each trial, we presented natural images of animals (spiders, snakes, and butterflies) in pairs with natural images of neutral non-animals (flowers and mushrooms) on both sides of the fixation cross with a varied time interval between the onset of the two stimuli. None of the pictures were cued. We assumed that spider pictures are automatically attended by spider-fearful participants compared to neutral pictures. Our participants had to judge which picture appeared first. We found that spider pictures induced a significant difference between the two groups. Spider-fearful participants perceived the spider pictures as occurring earlier in time compared to non-anxious control group and in comparison to snake and butterfly pictures. I conclude that phobic but not merely threat-relevant images show visual prior entry.

With these four experiments, I addressed three research questions which aim to fill important current research gaps. First, I wondered whether information processing of threatening stimuli measured by speeded responses in response priming paradigms is

enhanced in individuals with specific phobias? And in case information processing is enhanced for phobic images which neurophysiological mechanisms underlie this enhancement? Indeed, we were able to successfully demonstrate in Experiments 1, 2, and 3 (Chapter 2, 3, and 4) that natural images elicit response priming effects (measured in response times and error rates) and that these priming effects are modulated by the emotional significance of the presented images. Most interestingly, the modulated priming effects were already present in the fastest responses (i.e., in the 2nd and 3rd deciles of the response time distribution; cf. Sections 2.3., 2.4., 3.3 and 3.4). These results allow me to draw conclusions about the way phobic, threat-relevant and neutral images is processed considering the assumptions made by the rapid-chase theory (cf. Section 1.4.2. "The rapid-chase theory of response priming"). The rapid-chase theory links behavioral findings of response priming paradigms to recent findings that visual stimuli elicit a wave of neuronal activation (i.e., the feedforward sweep) which travels through the visuomotor system (Lamme & Rolfsema, 2000). Because the first sweep of neuronal activation is remarkably fast, Lamme and Rolfesema (2000) propose that this wave is purely feedforward and free of feedback from other cells. The rapid-chase theory states that both prime and target elicit a feedforward sweep of neuronal activation and predicts that the motor response should first be controlled exclusively by the prime signal and only later by the target signal. Because the theory assumes that the feedforward sweep of the target cannot catch up with that of the prime, it makes the strong prediction that response priming effects should be fully present in the fastest responses and should not increase any further in slower response times. This is exactly what we found in Experiment 1 and 3 (Chapter 2 and 4). We were not only able to find priming effects of neutral images but we were also able to find the modulatory influence of phobic images on priming effects in 2nd and 3rd deciles of the response time distribution. Therefore, we conclude that information processing of natural images in general and, specifically, information processing of phobic images is based on the first feedforward sweep of neuronal activation traveling through the visuomotor system.

Second, I was interested whether differences between the different types of phobia (e.g., spider phobia vs. snake phobia) occur? Contrary to our initial hypothesis, we found marked differences in priming effects and overall response times between different types of specific phobias – namely between spider- and snake-fearful

participants. These findings suggest that the modulatory effect by emotionally significant stimuli is driven by something beside emotion because spider- and snake-fearful individuals rated their phobic images of spiders and snakes comparably negative on the dimensions valence, disgust, and arousal. Furthermore, we found no indication that the two experimental groups differed in their fear level of spiders or snakes, respectively. These results allow me to draw further conclusion about the way phobic stimuli are processed. In contrast to the assumption that enhanced information processing is based on enhanced amygdala activation (cf. Section 2.4.1. "Underlying mechanisms of rapid information processing" and 6.2. "Enhanced information processing and the amygdala network"), the perceptual learning account can accommodate differential enhancement for different phobias. For instance, because the likelihood of encountering a snake is low for German participants compared to the likelihood of encountering a spider, our snake-fearful participants may have had less opportunity for perceptual learning than the spider-fearful participants, and less incentive for continued vigilance in interactions with their everyday environment. Additionally, if modulatory effects of phobic images are already present in the fastest response times this would put serious time constraints on any explanation involving the amygdala, especially considering the processing speed of the structures involved (cf. Piech et al., 2010; Tsuchiya et al., 2009). That means that the amygdala pathway would be required to (1) classify incoming stimuli as emotionally relevant, (2) outpace the cortical object recognition route, and (3) exert modulatory control on that processing route before it finishes processing the object. It is questionable whether all these processes can take place in the minimal time available in the rapid categorization task that we used, considering that all amygdala modulation of the object-recognition pathway must be finished before the fastest responses are completed. Mormann and colleagues (2011) analyzed response latencies from single neurons in the amygdala and found that they responded to animal pictures within 324 ms. That means significantly faster than to other image categories. The authors argue that this enhancement may reflect the biological importance of animals, but stress that "the observed amygdala latencies are nevertheless similar to those found in other regions in the temporal lobe, and thus seem more likely to be generated along the cortical object recognition pathway than via a rapid subcortical route" (p. 1248).

Based on our results of Experiment 1 to 3, I conclude that response priming is a useful instrument which can be easily adapted for research in the field of clinical psychology. Because response priming has a strong theoretical and empirical background, the findings allow me to make well-founded assumptions about the underlying neurophysiological mechanisms involved in the processing of neutral, threat-relevant, and phobic images. Accordingly, our results shed light on certain aspects of information processing which are usually not considered by recent literature. Additionally, response priming is not restricted to further investigate early information processing in individuals with anxiety disorders, but might also – for example – be applied to research on mood disorders (like depression), substance abuse, or obsessive-compulsive disorders.

Third, I was interested whether the frequently reported attentional bias of individuals with specific phobias also appear in temporal order judgments? To answer this question, we conducted a prior entry study in which we carefully controlled for the participating groups and applied conditions. Firstly, a control group took part in the experiment which enabled us to control for potential influences of image characteristics like spatial frequencies (cf. Chapter 5 and Section 6.4. “Pitfalls in emotion research”). Secondly, we applied three conditions (“spider vs neutral picture”, “snake vs. neutral picture”, and “butterfly vs. neutral picture”) These different conditions served as phobic, threat-relevant, and neutral conditions and allowed us to compare potential effects that occur within each group. Again, we found a specific influence of the phobic stimulus material on the participants' responses which was - comparable to the findings of Experiments 1 to 3 - restricted to phobic images and did not occur for threat-relevant, but non-phobic images.

In sum, the results of Experiment 1 to 4 show that individuals with specific phobia (i.e., spider and BII phobia) process their phobic images differently compared to non-anxious individuals and neutral images. Furthermore, merely threat-relevant images did not speed information processing in non-anxious control participants in neither of the four experiments. Most notably, we found differences between different types of phobia. I propose that these findings can be easily explained by long-term perceptual learning processes and a specific hardwired binding of elementary features belonging to the phobic object in fearful individuals (i.e., effortless recognition of the respective

phobic object via hardwired neuronal conjunctions). Furthermore, I suggest that perceptual learning processes might also strengthen the attentional bias, for example, by providing a more salient bottom-up signal that draws attention involuntarily. I believe that our results and the combination of response priming and prior entry paradigms allow me to draw well-founded conclusion about the underlying mechanisms of the processing of phobic images and the early attentional bias. Furthermore, in contrast to traditional paradigms (e.g., visual dot probe paradigm[18] or emotional stroop task[19]) response priming permits us to make distinct assumptions about *how* neutral, threat-relevant, and phobic images are processed in non-anxious and fearful individuals. However, I also want to emphasize that different methods like the prior entry paradigm we applied in the present thesis have to be considered to asses the different characteristics of specific phobias. Taken together, I conclude that (1) early information processing of threatening stimuli is indeed enhanced in individuals with specific phobias but that (2) differences between divers types of phobia exist and that (3) the frequently reported attentional bias of spider-fearful individuals is also detectable in a temporal order judgments.

As described above, two different accounts attempt to explain enhanced information processing by threatening stimuli: acceleration due to increased amygdala activation and long-term perceptual learning mechanisms. In the next two sections, I describe (1) how changes in the amygdala activation via the subcortical route might influence the processing of phobic images (Section 6.2.) and (2) how perceptual

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[18] Visual dot probe tasks are usually applied to measure the hypervigilance-avoidance pattern in individuals with anxiety disorders. Commonly, two stimuli - one neutral and one phobic - are presented for a varying time interval on the screen before a dot is presented on the position of one of the stimuli. Participants are asked to indicate the location of this dot as quickly as possible. It is assumed that faster responses to the dot occur if the dot appears on the location of the attended stimulus (e.g., Mogg & Bradley, 1999; MacLeod, Mathews, & Tata, 1986).

[19] Emotional stroop tasks are usually applied to measure information processing of emotionally significant words in contrast to neutral words. The presented word are written in different colors. Participants are asked to indicate the word color and response times are recorded. It is assumed that the response times to the color of emotionally significant words are slower compared to the response times of neutral words (e.g., Williams, Mathews, & MacLeod, 1996).

learning might change the functioning and structure of neurons in the visual system and in turn accelerate the speed in which phobic stimuli are processed (Section 6.3.).

6.2. Enhanced information processing and the amygdala network

It is frequently assumed that enhanced information processing of threat-relevant or phobic stimuli is mediated by changes in the neural activation of the amygdala. The processing of these stimuli should happen via a subcortical route of visual information processing and should be independent of attention and awareness (Tamietto & de Gelder, 2010). Consistent with that notion, several authors report (1) that threat-relevant faces are processed more rapidly and pre-attentively in visual-search tasks (e.g., Öhman, Lundqvist, & Esteves, 2001), (2) that subliminally presented fear-relevant faces are identified earlier compared to happy faces in continuous flash suppression tasks (Yang, Zald, & Blake, 2007), and (3) that amygdala activation increases in response to threat-relevant faces rendered unconsciously by backward masking (e.g., Morris, Öhman, & Dolan, 1998; Whalen et al., 1998).

However, the *exact nature* of the interaction between amygdala activation and enhanced information processing is typically not described. Originally, the assumption that subliminally presented visual stimuli are processed via a subcortical route has its roots in rodent studies which demonstrated that structures from the auditory thalamus to the amygdala are to some extent involved in Pavlovian fear conditioning (LeDoux, 1996). The idea of a similar subcortical route in humans is compelling since processing via this route is assumed to be faster than the cortical visual route and, indeed, the processing of threat-relevant and phobic stimuli in humans is very fast.[20] But *which* structures are said to be involved in the subcortical route of visual information and *what* are their roles?

First of all, the subcortical pathway is said to consist of the *superior colliculus*, the *pulvinar nuclei* and the *amygdala* whereas the pulvinar nuclei form the key link between the two other structures (Pessoa & Adolphs, 2010). The pulvinar complex, like other cortical areas involved in the visual system, has expanded during evolution and

[20] Note that because information processing of emotionally relevant stimuli is assumed to be subcortical, it is suggested that information processing of affective visual stimuli should be coarse (e.g., is based on low-spatial frequencies; cf. Vuilleumier, Armony, Driver, & Dolan, 2003).

forms the largest complex of nuclei in the primate thalamus (Grieve, Acuña, & Cudeiro, 2000). It receives direct input from the retina, indirect input via the superior colliculus and extensive input from the striate and extrastriate visual cortices. At a first glance, this appears to make the pulvinar complex a likely candidate for a route of fast information processing.

Indeed, the pulvinar complex plays an important role in attention and visual awareness. First, a majority of pulvinar cells inhibit responses to stimuli which are task-irrelevant in contrast to task-relevant stimuli (Benevento & Port, 1995). Additionally, activation of the pulvinar complex only increases in case the monkey attends to a stimulus (Petersen, Robinson, & Keys, 1985). Second, the pulvinar complex is associated with awareness; more specifically, with visual neglect and deficits in feature binding (Zihl & von Cramon, 1979; Karnath, Himmelbach, & Rorden, 2002; Ward, Danziger, Owen, & Rafal, 2002). For example, a fMRI study by Padmala, Lim, and Pessoa (2010) demonstrated that the pulvinar nuclei do not respond to the affective valence of a stimulus, but to whether or not the stimulus is consciously perceived. This directly contradicts the frequently made assumption that the pulvinar is involved in unconscious processing (Pessoa & Adolphs, 2010). Taken together, evidence exists that the pulvinar complex plays an important role in attention and visual awareness.

However, Pessoa and Adolphs (2010) also report a number of studies indicating that the input from the superior colliculus does not reflect the visual response properties of the pulvinar nuclei. For instance, a study by Bender (1983) showed that lesions in the superior colliculus has little effect on electrophysiological responses of the pulvinar complex in contrast to lesions of the primary visual cortex (cf. de Gelder et al., 2010). This directly challenges the notion of a visual pathway progressing from the superior colliculus via the pulvinar nuclei to the amygdala. In contrast, it is more probable that the pulvinar nuclei are part of a more wide-spread cortical network (Pessoa & Adolphs, 2010). Still, the critical question, based on the findings reported above, is whether a subcortical route also exists in humans and, specifically, in human vision?

Monkey studies showed that there are in fact neuronal connections from the superior colliculus to the *inferior* pulvinar (Grieve et al., 2000) and from the pulvinar nuclei to the amygdala (Jones & Burton, 1976; Romanski, Giguere, Bates, & Goldman-Rakic, 1997). However, the connections to the amygdala are only from the *medial*

pulvinar and not from the *inferior* pulvinar (Jones & Burton, 1976; Romanski et al., 1997). Hence, a direct colliculus-pulvinar-amygdala pathway seems to be unlikely solely from an anatomical viewpoint (Pessoa & Adolphs, 2010). Given that a subcortical route of information processing is implausible, which role does the amygdala play in visual information processing of emotionally relevant stimuli at all?

According to Pessoa and Adolphs (2010), the amygdala's most prominent feature is its connectivity to the visual cortex and higher-order visual cortical areas, but also to the frontal and prefrontal cortex (Averbeck & Seo, 2008; Ghashghaei, Hilgetag, & Barbas, 2007). Due to its feedback loops to the visual cortex, the amygdala most probably has a modulatory role in the processing of visual input (Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). Additionally, the amygdala belongs to the "core brain circuit" (Modha & Singh, 2010) which is a central structure in terms of global connectivity within the brain suggesting that its major role is the aggregation and distribution of information. Consequently, Pessoa and Adolphs (2010) propose that the amygdala can mediate behavior through many routes (e.g., via both the visual and the prefrontal cortex). This notion is supported by the results of a study by Lim, Padmala, and Pessoa (2009). They demonstrated in a task combining attentional blink and fear conditioning that trial-by-trial fluctuations in the amygdala evoked by emotionally relevant stimuli predict target detection. Furthermore, they found that responses of the amygdala and the visual cortex is highly correlated. Correspondingly, statistical path analysis showed that the modulatory effect of the amygdala on behavior was mediated by the visual cortex and prefrontal cortex. Thus, the amygdala enhances processing of emotionally relevant stimuli directly (via the amygdala-visual cortex pathway) and indirectly (via the amydgala-prefrontal cortex-visual cortex pathway) but not via a subcortical pathway (cf. Pessoa & Adolphs, 2010).

A synopsis of all these findings suggests that the subcortical pathway via the superior colliculus, pulvinar nuclei, and amygdala does not play the role that was ascribed to it by many authors (e.g., by Öhman & Mineka, 2001; by Tamietto & de Gelder, 2010). Indeed, these structures are important for the processing of visual stimuli but their functions are different than frequently proposed. A subcortical processing of emotionally relevant stimuli via the colliculus-pulvinar-amygdala pathway as opposed to a cortical pathway seems to be highly implausible.

However, there is striking evidence that emotionally relevant stimuli are indeed preferentially processed in individuals with specific phobias. In the next chapter, I will provide an alternative explanation for this enhancement in information processing.

6.3. Enhanced information processing and perceptual learning

In the following, I first summarize *why* researchers believe that perceptual learning can lead to changes in the neural hierarchy of the visual system and report the most significant findings in this research field (Section 6.3.1.). Second, I describe *how* these changes in the visual system might enable enhanced information processing of phobic images (Section 6.3.2.).

6.3.1. Perceptual learning and hardwired binding

According to Gilbert and colleagues (2001) perceptual learning "is a lifelong process [in which] We begin by encoding information about the basic structure of the natural world and continue to assimilate information about specific patterns with which we become familiar" (p. 681). More specifically, we implicitly learn to discriminate different stimuli when we are frequently confronted with them. Research on perceptual learning processes and, thereby, on neural plasticity has substantially increased in the last few decades. The changes in the neural organization also affect early visual stages like the primary visual cortex (V1; the first cortical area in which visual processing takes place), V2, and V4.[21] These early stages are reasonably well understood in terms of receptive fields and neocortical circuits. Originally, it was assumed that plasticity in sensory areas is restricted to newborns and rapidly decline as the child gets older. The idea that neural plasticity also affect the primary visual cortex in adults is relatively new (Gilbert et al., 2001).

Thus, researchers showed that training (i.e., perceptual learning) improves the discrimination of the trained stimuli. For example, Fiorentini and Berardi (1980, 1981) demonstrated that the benefits of discrimination training on complex grid patterns led to

[21] Later visual stages in object recognition involve cortical areas in the ventral visual pathway, like the inferotemporal cortex and the medial temporal lobe (MT). Neurons in V1 represent the detailed features of a stimulus whereas neurons in higher areas of the visual system respond to more complex representations of the object (e.g., Quiroga, 2012).

an improved performance. Similar results were reported for discrimination training in vernier acuity (i.e., the ability to decide if one of two lines that are presented on top of each other is slightly displaced to the left or right; McKee & Westheimer, 1978), orientation (Vogels & Orban, 1985), motion (Ball & Sekuler, 1982, 1987), and depth perception (Fendick & Westheimer, 1983; Ramachandran & Braddick, 1973).

However, Fiorentini and Berardi (1980, 1981) also demonstrated that the training effects vanished in case the trained pattern was rotated by 90 degrees. The same effect occurred when the trained stimulus was tested at an untrained position (e.g., Ball & Sekuler, 1987; Karni & Sagi, 1991). Gilbert and colleagues (2001) conclude that training in perceptual discrimination tasks most likely involve early visual stages considering (1) "that stimulus features are represented with the finest resolution" (p. 682) and (2) that the training effects vanish when the small receptive fields of the early visual stages are changed during the task.[22]

Gilbert and colleagues (2001) argue that also complex features can be successfully trained. For example, Westheimer and colleagues (Fendick & Westheimer, 1983; Fahle & Westheimer, 1988; Westheimer & Truong, 1988) showed that an improvement in depth perception as a consequence of training also depended on the the spacing of the trained elements and the surrounding context. In other words, perceptual learning did not only encompasses the discrimination between single stimulus features but also the context in which stimuli are presented. Furthermore, it was also shown that perceptual learning lead to a preference of neurons in higher cortical areas for the trained stimuli like the inferotemporal cortex (Sakai & Miyashita, 1994) which plays a role in object recognition (Tanaka, Saito, Fukada, & Moriya, 1991) and in the middle temporal cortex (Zohary, Celebrini, Britten, & Newsome, 1994) which plays a role in motion perception and guidance of eye movements (Born & Bradley, 2005).

[22] Note that in the visual system, the receptive field of a neuron is defined by the area of the retina to which a (preferred) stimulus must be presented to evoke a response (i.e., increases or decreases the neuron's firing rate). The whole retina is covered by a mosaic of receptive fields (Rosenzweig, Breedlove, & Watson, 2005). Consequently, when a small stimulus is presented in the visual field, only those neurons whose receptive fields are in the corresponding part of the retina respond to that stimulus. Hubel and Wiesel (e.g., 1959) propose that the small receptive fields of simple feature cells in early stages of the visual system are combined into larger receptive fields of complex feature cells in higher levels of the visual system.

Consequently, we can assume that not only simple object features (e.g., the orientation) but also complex shapes like (e.g., spiders) can be trained by perceptual learning processes. Thus, these learning processes might enhance information processing of phobic stimuli.

I conclude that the processing of complex stimuli is suspect to perceptual learning processes. This learning, or training, leads to an increasingly automatic processing of complex stimuli that is possible without requiring additional attentional resources. I propose that this is exactly what happens in phobic or fearful persons. In Experiment 1 and 2 (Chapter 2 and 3) we demonstrated that spider-fearful individuals show enhanced information processing of the phobic stimuli in contrast to snake-fearful participants. I propose that the perceptual learning account can also accommodate differential enhancement for different phobias. For instance, because the likelihood of encountering a snake is low for German participants compared to the likelihood of encountering a spider, snake-fearful participants may have had less opportunity for perceptual learning compared to the spider-fearful participants, and less incentive for continued vigilance in interactions with their everyday environment. However, we also demonstrated that spider- and BII-fearful individuals show enhanced information processing of spiders and injuries compared to the non-anxious control groups despite that spiders and injuries are also encountered in everyday life for these participants. I suggest that the hypervigilance pattern frequently reported in the literature (cf. Chapter 1.5. "Attentional biases in specific phobias") plays an important role in the initiation of perceptual learning processes. Since phobic stimuli like spiders and injuries are attended more often by fearful compared to non-anxious individuals, perceptual learning is more likely for these stimuli. Additionally, the confrontation with phobic stimuli are accompanied by negative emotions which might extra enhance perceptual learning processes. But, which concrete physiological changes in the neural structure or the functioning of neurons are induced by perceptual learning?

6.3.2. The neural basis of perceptual learning

As described above, the idea that the adult primary visual cortex is subject to neuronal plasticity is relatively new. For example, in a classical study (Wiesel & Hubel, 1965; cf. Fahle, 2003), it was demonstrated that when one eye of a kitten is sewn shut, the resulting changes in the cortical hierarchy due to visual deprivation are only

reversible until the adolescence of the animal. However, first evidence that neurons of the primary sensory cortex are alterable came from studies with adult monkeys by Merzenich and colleagues (Merzenich et al., 1983, 1984). The authors demonstrated that after the amputation of a finger the sensory cortex of the monkeys was reorganized such that neurons formerly responding to the ablated finger started to respond to the adjacent fingers of the hand. This plasticity of neurons was also demonstrated for V1. For example, studies demonstrated that, initially, retinal lesions silenced the affected cortical areas. However, after a certain time period, the respective receptive fields in V1 were shifted towards unaffected regions close to the lesion (Gilbert & Wiesel, 1992; Kaas et al., 1990).

However, not only cortical lesions induce neural plasticity. Also perceptual learning processes in an unscathed brain might alter the neural representation of a stimulus in several ways. First, the representation of a trained feature or stimulus may increase in size. For example, Nudo, Milliken, Jenkins, and Merzenich (1996) showed that when monkeys are trained in forearm movements the cortical representation of the forearm in the motor cortex expands (i.e., the cortical surface of motor responsive areas becomes larger). Furthermore, Recanzone, Schreiner, and Merzenich (1993) demonstrated that when owl monkeys were trained to discriminate between small differences in the frequency of tones, the auditory cortex showed an increase in the size of the representation of the trained frequencies (also cf. Xerri, Merzenich, Peterson, & Jenkins, 1998). Interestingly, the increase in the size of cortical representation of a trained stimulus does not decrease the size of non-trained representations suggesting that as a result of training more information can be stored in a given cortical area.

Second, the tuning curves of neurons might be sharpened. The tuning curve describes the specificity of a population of neurons to a specific stimulus feature (e.g., orientation).[23] The neurons with the highest sensitivity for the orientation of a presented stimulus respond most strongly in terms of spikes per second. The adjacent neurons which are less sensitive to this orientation but sensitive to a similar orientation respond less strongly. The resulting (typically bell-shaped) tuning curve can be sharpened via learning. Prior to training, the cells of a given neuron population are selective for similar

[23] For the recording of population tuning curves integrating the responses of single neurons see, for example, Martínez-Trujillo & Treue (2002).

but different features; after training more cells of the population are most sensitive to the feature (e.g., orientation) of the trained stimuli (Gilbert et al., 2001). As a result, the tuning curve of the population (i.e., activation of its neurons) increases for the trained feature and decreases for the other (similar) features. Accordingly, Weinberger and colleagues (1990) as well as Recanzone and colleagues (1993) demonstrated that animals who were trained to discriminate different auditory frequencies showed a sharpening of population tuning curves and a shift towards the trained frequencies.

Third, Gilbert and colleagues (2001) propose that perceptual learning leads to a shift in the locus of representation. Originally, it was assumed that simple stimuli with a single feature are encoded in early stages of the visual system, while complex stimuli which require the combination of these single features are encoded in later stages (Hubel & Wiesel, 1959). Furthermore, it was proposed that the combination of several single features is time-consuming and demands attentional resources (Treisman & Gelade, 1980). In contrast, Gilbert and colleagues (2001) assume that the processing of complex, but familiar stimuli might be shifted from later to earlier stages of the sensory system. They propose that features of familiar (i.e., "overlearned") stimuli have a special significance. Therefore, these features can be processed in an automatic and parallel fashion by neurons in early stages of the visual system. Consequently, it is easy to find the number "5" between an array of number distractors ("2"). However, this task becomes harder and requires attentional resources when the array is rotated by 90 degrees (Wang, Cavanagh, & Green, 1994), because numbers are only familiar in a vertical orientation.

Complementary, VanRullen (2009) impose the idea of *hardwired binding* of features. Originally, it was assumed that object recognition depends on *on-demand binding* during which the separately coded features of a presented stimulus are bound into one object. This process is assumed to require attentional resources (cf. Treisman & Gelade, 1980). On the other hand, one important goal of learning is to decrease the level of attention which is needed to accomplish a certain task (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). In contrast to the on-demand binding account, hardwired binding of features does not require attentional resources because elementary features can be bound by higher level neurons into hardwired combinations. Supporting this hypothesis, several studies were able to show that the categorization of natural images

(i.e., stimuli that are encountered in everyday life) by means of speeded motor responses is indeed very rapid (Kirchner & Thorpe, 2006; Thorpe et al., 1996).[24] As described in Section 1.4.2. "The rapid-chase theory of response priming", these findings suggest that the processing of natural images is most likely based on the first feedforward sweep traveling through the visual system (Lamme & Roelfsema, 2000; Schmidt & Schmidt, 2009; VanRullen & Thorpe, 2001). Indeed, it was shown that the temporal distribution of the first spikes can already code for most of the stimulus-relevant information (*spike-timing-dependent plasticity;* Guyonneau, VanRullen, & Thorpe, 2005; Masquelier, Guyonneau, & Thorpe, 2009). The *rapid-chase theory* by Schmidt and colleagues (2006) provides a framework for rapid visual information processing based on the first feedforward sweep. The theory proposes that the motor response measured in response priming paradigms should first be controlled exclusively by the prime signal and only later by the actual target signal. Because one assumption of the theory is that the feedforward sweep elicited by the target cannot catch up with that of the prime signal, it makes the strong prediction that response priming effects should be fully present in the fastest responses and should not increase any further for longer response times. This is exactly what we found in Experiment 1 and 3 (cf. Chapter 2 and 4).

I conclude that the neural plasticity of the visual system (but also of other sensory cortical areas) is not restricted to early post-natal stages, but can also occur in adult learning. These physiological changes can be induced via training (i.e., perceptual learning) and are accompanied by changes in the structure of the neuronal representation of a stimulus - in the firing rates of sensitive neurons, in the locus of stimulus representation and/or in the temporal distribution of the first spikes. Additionally, perceptual learning might lead to hardwired binding which means that the features of familiar objects are automatically bound together and, therefore, no attentional resources are necessary for their categorization. Spider- and BII-fearful individuals attend frequently to the respective phobic stimuli. I suggest that these stimuli are well trained by the fearful individuals which might lead to a higher sensitivity of neurons towards phobic stimuli, to a larger representation of these stimuli, to changes in the temporal distributions of the first spikes in the first feedforward

[24] For instance, Kirchner and Thorpe (2006) demonstrated using a forced-choice saccade task that participant reliably classified images as containing an animal or not by saccades in as little as 120 ms.

sweep, or a combination of these described changes. As discussed in Section 2.4.1. "Underlying mechanisms of rapid information processing", the perceptual learning approach can well account for our results in Experiment 1, 2, and 3, whereas the assumption that the modulation of response priming effects is due to enhanced amygdala activation is challenged by the time constrains of our results.

6.4. Pitfalls in emotion research

In Experiment 4, we demonstrated that a prior entry effect occurs for spider pictures in spider-fearful participants. The effect, though, is small (Effect sizes of Cohen's *d*, cf. Section 5.3. and 5.4.) even in participants with a specific fear of spiders.[25] Nevertheless, attentional biases are frequently reported the current literature. I believe that a variety of mechanisms – beside emotionality of the stimulus material – can lead to attentional biases and that these effects may be misattributed to the emotionality of the stimuli. These mechanisms comprise bottom-up as well as top-down processes of attention. I will discuss some of them and their possible influence on the present results.

6.4.1. Stimulus characteristics

The starting point of conducting the prior entry study reported in the present thesis (Experiment 4, Chapter 5) were the studies by West and colleagues (2009) and Fecica and Stolz (2008).[26] In the two studies, the researchers used threat-relevant and neutral face stimuli and reported a prior entry effect for threat-relevant stimuli in non-anxious participants. Accordingly, West and colleague (2009) concluded that their study "provides direct evidence of the extent to which motivationally significant stimuli capture attention over other concurrently displayed items in the visual array" (p. 1032). Yet, I believe that their effects may be explained at least in part in terms of confounds in low-level vision (e.g., orientation, color) in the stimulus material used in their study.

[25] This impression was further supported by a personal conversation on ECVP 2012 with Dr Michael Pilling who applied roughly the same paradigm as we used in Experiment 4 (Chapter 5). Pilling and his colleagues were not able to demonstrate a prior entry effect using a sample of non-anxious control participants. This suggests that attentional biases for threat-relevant pictures in non-anxious participants are rarely detectable.

[26] Note that these are the only two studies I know of which used the method of temporal order judgments to demonstrate that threat-relevant stimuli capture attention.

Furthermore, I believe that the paradigm they applied was not adequate to control for these effects.

First of all, the authors used schematic faces in four of their six experiments and assumed that these stimuli are motivationally significant. However, several recent studies (cf. Coelho, Cloete & Wallis, 2010; Becker et al., 2011; Horstmann, 2007; Horstmann & Bauland, 2006; Stein & Sterzer, 2012) cast doubt on the validity of schematic faces in emotion research. Researchers started to use schematic faces in response to the criticism that the frequently found *face in the crowd effect* (i.e., the effect that faces with threatening expressions are more rapidly detected in contrast to faces with neutral expressions) are due to low-level differences in the images of real faces rather than biological preparedness (Coelho et al., 2010). Consequently, researchers assumed that the schematic versions of emotional faces control for this effect.

Unfortunately, the use of schematic faces leads to other confounds. For example, Coelho and colleagues (2010) conducted a series of visual search experiments and demonstrated that an advantage in search times for angry schematic compared to happy schematic faces indeed exists. However, they also showed that stimuli with oblique oriented lines and with curved mouth-like elements elicit a comparable effect. According to the authors, these results "suggest that low-level features probably underlie the face-in-the-crowd effect described for schematic face images, thereby undermining evidence for a search advantage for specific facial expressions" (Coelho et al., 2010, p. 1). Moreover, Becker and colleagues (2011) conducted seven experiments using schematic faces that carefully controlled for confounds of low-level characteristics. They found no advantage in detecting angry faces, but in contrast, found an advantage in detecting happy faces. Several other recent studies challenge the use of schematic images in emotion research and conclude that the demonstrated effects are most likely based on low-level characteristics of the schematic faces (Horstmann, 2007; Horstmann & Bauland, 2006; Stein & Sterzer, 2012).

These findings show that researchers should carefully control their stimulus material concerning the influence of confounding variables. One way to control for the influence of low-level characteristics is the implementation of a non-anxious control group similar to what we did in Experiments 1 to 4. Our present experiments are based

on the assumption that the control and experimental groups differ in respect to their emotionality. In other words, in case we find an effect in the experimental group, but not in the control group, we can rule out differences in low-level vision; in case we find a comparable effect in the two groups, influences of low-level vision must be considered. However, a control group cannot be implemented in every paradigm. Therefore, suitable control stimuli should be considered. For instance, West and colleagues (2009) could have considered using neutral control stimuli in their study (e.g., like the control stimuli in Coelho et al., 2010) and pair them with neutral schematic face stimuli.

6.4.2. Expectancy

A top-down mechanism which may influence the attentional bias is expectancy. Devue and colleagues (2011) used an additional-singleton task. In this task, participants searched for a circle and responded to the orientation of a line within that circle. In their first experiment, the authors additionally presented a spider or butterfly distractor on the screen. They found that the performance deteriorated in spider-fearful participants each time one of the distractors appeared, independent of its type. In the second experiment, Devue and colleagues (2011) presented the distractors in blocks (i.e., in each block either spider or butterfly detectors were presented). The authors found that in that condition performance solely was impaired in blocks containing spider distractors, but not in blocks where butterfly distractors were presented. The authors concluded that performance is only affected in cases in which spider-fearful participants expect spiders to appear and wrote, "Our results show that people that fear spiders inspect potential spider-containing locations in a compulsory fashion even though directing attention to this location is completely irrelevant for the task" (Devue et al., 2011, p. 1; also see Bermpohl et al., 2006).

I assume that expectancy does not play a major role in Experiments 1 to 3 (Chapter 2 to 4) of the present thesis because neutral, threat-relevant, and phobic pictures were randomly presented and not presented in blocks. That means that, for example, spiders appeared frequently and unpredictably across each session. However, expectancy might have influenced the results of Experiment 4 (Chapter 5). In that experiment, animals were presented in blocks (i.e., in each block either spiders, snakes or butterflies appeared). Therefore, it would be interesting to compare our results to a

paradigm in which the animal pictures are not presented in blocks, but randomly presented trial by trial. In case expectancy increases attentional capture, I would assume to find smaller prior entry effects in this experiment.

6.4.3. Sample characteristics

Differences in sample characteristics might also lead to contradictory results. For instance, several studies report effects in information processing and/or attentional bias of threat-relevant stimulus material in non-anxious control groups (e.g., Anderson & Phelps, 2001; Öhman, Flykt et al., 2001; Piech et al., 2010). However, we were not able to find these effects in any of our experiments (also cf. Tipples et al., 2002). The conflicting findings suggest that non-anxious control participants in various studies may differ in research-relevant characteristics, for example in their trait/state anxiety (see, e.g., Koster et al., 2005; Mogg et al., 2004).

Furthermore, depression questionnaires should be applied in every study measuring rapid information processing and/or attentional biases. In a study by White and colleagues (1997), the authors demonstrated that depression slows response times (also cf. McDermott & Ebmeier, 2009). In studies where fast responses are crucially important, depression questionnaires should also be used for non-anxious control participants. Likewise, studies showed that robust attentional biases exist in individuals with anxiety disorders. However, Mogg and Bradley (2005) summarized in their review article that attentional biases are less stable in participants with clinical depression. Generally, depression is more frequently reported in individuals with anxiety disorders (Wittchen et al., 2000). However, it can also occur in participants in the non-anxious control group. I conclude that depression questionnaires should be used in studies measuring fast information processing and/or attentional biases even if the sample consist of non-anxious individuals.

6.5. Summary

In the present thesis, I was able to demonstrate that information processing of visual phobic stimuli is enhanced, and, additionally, that this processing differ between different types of specific phobia (i.e., spider phobia and BII phobia vs. snake phobia). The empirically and theoretically well-founded method of response priming allows me

to draw funded assumption how these stimuli are processed. Based on our findings, we conclude that processing of images in general is most probably based on the first sweep of neuronal activation (i.e., the first feedforward sweep) which travels through the visuomotor system. Most interestingly, the already rapid information processing of natural images is further enhanced for phobic images in the respective fearful group. We assume that this further enhancement can be easily explained by long-term perceptual learning processes and in terms of hardwired binding (i.e., effortless recognition of the phobic objects via hardwired neuronal conjunctions). These findings are in contrast to the frequently reported assumption that the amygdala plays a major role in the processing of phobic and threat-relevant stimulus material. Based on our results of the first 3 experiments, I conclude that response priming is an excellent method which is able to reveal the underlying mechanisms of rapid information processing of natural images in general and of phobic images specifically. Also, it can be easily adapted for research in the field of clinical psychology. Additionally, we were also able to demonstrate that the frequently reported early attentional bias in individuals with specific phobia is strong enough to trigger a prior entry effect of spider images in spider-fearful individuals. I propose that these findings can also be explained by long-term perceptual learning processes in the way that perceptual learning might strengthen the attentional bias by providing a more salient bottom-up signal for phobic images.

Closing, I conclude that (1) early information processing of threatening stimuli is indeed enhanced in individuals with specific phobias but that (2) differences between divers types of phobia exist and that (3) the frequently reported attentional bias of spider-fearful individuals is also detectable in a prior entry paradigm measured by temporal order judgments.

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