
11 Integrating Behavioral and Electrocortical Measures of Attentional Bias Toward Threat

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INTRODUCTION

The term *attention* is typically used to refer to a set of processes that control the flow of information through the nervous system, modulating perceptual, motor, and response systems. One type of attention, termed *selective attention*, allows individuals to select specific objects in their environment for enhanced processing—a mechanism that is integral to successfully navigating a complex and dynamic environment. Selective attention for threatening stimuli is often referred to as an attentional bias toward threat, and may even be integral to the survival of a species, serving as the mechanism that allows for the quick assessment of potential sources of harm in the environment.

For example, human beings who could more rapidly identify the arrival of a predator in the environment would have been better positioned to escape or more prepared to fight. Because an attentional bias toward threat should have increased odds of survival, the human brain may have evolved to preferentially process these stimuli (LeDoux, 1998). Nevertheless, attention toward threatening stimuli does not go unchecked—human beings possess large prefrontal cortices, which permit us to *direct* attention toward whatever stimuli in the environment are in line with ongoing priorities (Corbetta & Shulman, 2002; Semendeferi, Lu, Schenker, & Damasio, 2002). Therefore, recent research has questioned the extent to which threatening stimuli capture attention preferentially, especially when their processing is at odds with task demands.

ATTENTION TOWARD THREAT IN THE LABORATORY

Whether and how attention is preferentially allocated toward threatening stimuli can be explored in the laboratory. To this end, researchers have developed tasks that use threat analogs. Threat analogs can be images that depict humans being attacked by other humans, or images of humans or animals directing attack toward the viewer (e.g., a man pointing a gun at the viewer or a vicious dog lunging at the camera). Non-threatening stimuli are used for comparison and include images of human faces with neutral expressions, non-threatening animals, and household objects, for instance. To facilitate the comparison of results between laboratories and studies, threatening and non-threatening stimuli are often selected from standardized sets such as the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). There are also standardized sets of facial expressions (e.g., the Ekman series, Ekman & Friesen, 1976; the NimStim series, MacArthur Research Network on Early Experience and Brain Development, 2002), which depict actors displaying a variety of emotions such as fear, sadness, anger and happiness. Threatening facial stimuli are typically faces that display anger or fear; anger represents a direct threat, whereas a fearful face suggests the presence of threat in the environment.¹

In designing tasks to examine attention toward threat, researchers have assumed that if threatening stimuli capture attention, then people should be especially quick to locate these stimuli (i.e., in comparison to non-threatening stimuli). This type of attention is often called “bottom-up” attention, and refers to the notion that some stimuli capture attention because they are naturally motivationally salient. In other words, the content of some stimuli (e.g., the smell of food when we are hungry) seem to naturally capture and direct our attention. Contrariwise, “top-down” attention refers to attention that is allocated toward stimuli because of task instructions or our own decisions regarding what is important. Continuing the example above—if we are hungry, yet we are in a meeting with colleagues and it is still an hour until lunch, we might use top-down mechanisms of attention to focus on what is being said in the meeting. Bottom-up and top-down attention can work in tandem—for instance, if threatening stimuli are also task-relevant, then task performance should be improved. By contrast, when top-down and bottom-up attention are in conflict, such as when threatening stimuli are task irrelevant (e.g., when searching for a non-threatening stimulus among an array of threatening stimuli), the facilitated detection of threatening stimuli may slow performance or lead to less accurate responses.

In this way, behavioral measures can be leveraged to index the capture of attention by threatening stimuli. Specifically, researchers have designed tasks for which attention toward threatening stimuli is expected to improve performance on certain trials and worsen performance on other trials. By comparing performance measures on such trials, it is possible to estimate the extent to which participants attend preferentially to threatening stimuli.

Many of these tasks assess the allocation of *visual spatial attention* to threatening versus non-threatening stimuli. For example, in the dot-probe task, participants view a pair of images (e.g., an angry face and a neutral face) presented simultaneously in different locations on a computer screen. Following picture offset, a target (e.g., a dot) appears where the threatening or the non-threatening image was previously presented, and participants must respond to, or categorize, this target as quickly as possible. Faster responses when targets replace threatening compared to non-threatening stimuli suggest that participants were attending to the location of the threatening stimuli prior to target onset—thus facilitating reaction time to the target and indicating an attentional bias toward threat. When participants are faster to respond to target stimuli that replace non-threatening compared to threatening stimuli, or if reaction times are equivalent across trial types, then there may be an attentional bias *away* from threatening stimuli, or no attentional bias at all, respectively.

Behavioral measures have been used extensively to index attention toward threatening stimuli, and provide observable indices of the effects of attentional biases. However, because reaction time and error rate are several steps removed from the actual allocation of attention to target stimuli, a great deal of noise (e.g., variability in motor response, decision making, etc.) may be introduced in behavioral measurements of attentional bias toward threat. As a result, attentional effects may be difficult to measure, particularly when effects are not very strong (as may be the case in nonanxious populations). Additionally, in some behavioral tasks, responses are made to targets that *replace* threatening and non-threatening stimuli, and can therefore only provide an *indirect* measure of the actual allocation of attention to the previous threatening stimulus. By contrast, neural activity can be measured in response to threatening stimuli themselves (rather than to targets that replace threatening stimuli)—and is a much more temporally proximal measure of attention. For example, attention shifts toward threatening stimuli even before participants look at those stimuli, and neural activity can reflect this shift in attention several hundred milliseconds before participants respond with a button press. In addition, neural activity is not subject to participants’ efforts to compensate for the effects of attentional biases in the same way as behavioral response, and may therefore be more effective at indexing attentional biases in certain tasks or participants.

Given these benefits of neural measures, researchers have recently begun to incorporate them in the investigation of attentional biases toward threatening stimuli. This chapter focuses on the application of event-related potentials (ERPs) to the study of attentional biases toward threatening stimuli. ERPs arise from intracortical currents induced by excitatory and inhibitory post-synaptic

potentials that result from the release of neurotransmitters. They provide a millisecond by millisecond index of electrocortical activity distributed across the scalp and are ideally suited to indexing *when* activity takes place in the brain. ERPs are time-locked to events; for example, ERPs may be examined following the presentation of a pair of faces (“cue-locked”) or following the presentation of a target that replaces a threatening or neutral face (“target-locked”). By averaging electrocortical signals at individual sites and across multiple trials, average amplitudes can be compared between trial types (e.g., trials on which a dot replaced a threatening face compared to trials on which a dot replaced a neutral face). Interpreting the meaning behind larger or smaller ERPs is not always intuitive, but a robust literature exists on the ERP methodology. ERPs have been used extensively since the 1960s, and many ERP components are now well-established neural indices of specific attentional processes (e.g., visual spatial attention—the N2pc; see section below on ERPs). In sum, ERPs can provide a highly sensitive index of the dynamic allocation of attention toward threatening stimuli, and the ways in which ERPs can be used alone or in conjunction with behavioral measures to index attention toward threatening stimuli are the major focus of this chapter.

ATTENTION TOWARD THREAT IN ANXIETY

Although increased attention to threatening stimuli may generally be adaptive, there are many ways in which attention to threat can go awry. For example, a person might be hypervigilant for threatening stimuli and might devote an excessive amount of resources toward monitoring his environment; he may have a low threshold for threatening stimuli so that even non-threatening or mildly threatening stimuli routinely capture attention; or, he may have difficulty disengaging attention from threatening stimuli, once detected. Various abnormalities in attention toward threatening stimuli may underlie and serve to maintain anxiety disorders (Beck & Emery, 1985; Eysenck, 1997; Eysenck, Derakshan, Santos, & Calvo, 2007; Mathews & MacLeod, 2002). For instance, a person with social anxiety might scan a crowd in search of disapproving faces, might perceive even neutral faces as disapproving, and might find it difficult to shift attention to other, more approving faces once disapproving faces have been discovered. As a result, a person with social anxiety might overestimate the level of threat in the environment, which could serve to confirm and increase social fears. Though most cognitive theories of anxiety suggest a prominent role of increased vigilance for threatening stimuli, there are disagreements as to the precise mechanisms that support this bias.

For example, some theorists have suggested that anxiety is best characterized by a lower *threshold* for threatening stimuli (Mogg & Bradley, 1998). In other words, anxious individuals may selectively attend to mildly or non-threatening stimuli. Thus, neutral faces may go unnoticed in a nonanxious individual, whereas a socially anxious person might become aware of these faces because they are *not* smiling. If this is the case, it would be expected that, compared to nonanxious individuals, anxious individuals would demonstrate greater attentional biases toward *mildly* threatening stimuli.

Other theorists have suggested that anxious individuals are fundamentally distinguished from nonanxious individuals by greater difficulty *disengaging* from threatening stimuli once these stimuli are attended (Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Yiend & Mathews, 2001). Posner and colleagues (Posner & Petersen, 1990; Posner, Walker, Friedrich, & Rafal, 1984) have identified three types of visuospatial attentional operation. Namely, attention engages with a stimulus at a certain location, then it must disengage from its current location and shift to a new location (in order to engage with the stimulus at the new location). Anxious and nonanxious individuals may both initially engage with threatening stimuli, because this is adaptive. However, once engaged with threatening stimuli, anxious individuals might have greater difficulty *disengaging* from them to shift attention to other stimuli in the environment. This might be evidenced by greater behavioral interference from task-irrelevant threatening stimuli that are presented for longer durations.

Some theorists have suggested that anxiety is associated with enhanced early attention for threat but subsequent avoidance of threat (Mogg, Bradley, De Bono, & Painter, 1997; Williams, Watts, MacLeod, & Mathews, 1997). From this perspective, an anxious individual would continually

monitor his environment for threatening stimuli (i.e., hypervigilance), however, once a threatening stimulus was detected, the anxious individual would shift attention away from the threatening stimulus, presumably to avoid distress associated with the threat. This attentional pattern would be characterized by an initial threat-related processing enhancement, followed by a subsequent decrement.

There is evidence to support all of these views of attention in anxiety (delayed disengagement; Amir, Elias, Klumpp, & Przeworski, 2003; Fox et al., 2002; and vigilant-avoidant processing of threat; Mogg, Bradley, Miles, & Dixon, 2004; Weinberg & Hajcak, *in press*) and differences in task design may explain some of these discrepancies. For example, when threatening stimuli are presented rapidly and threat is irrelevant to the task at hand, anxious individuals may exhibit increased attention toward threat (MacNamara & Hajcak, 2009, 2010). Contrariwise, when stimuli are presented for longer (e.g., in passive viewing), anxious individuals might be characterized by initial vigilance for, and subsequent avoidance of, threatening stimuli (Weinberg & Hajcak, *in press*). In this way, different task designs might be associated with relatively more automatic versus strategic processing of threatening stimuli.

It is important to understand the temporal characteristics of attention toward threat in anxiety, because of the implications for understanding the way anxiety is maintained and treated. For example, according to the vigilance-avoidance hypothesis, anxious individuals may rapidly detect threats, but never have the opportunity to habituate to feared situations or objects because threatening stimuli are quickly avoided.

This chapter reviews basic work on attentional biases toward threat and how this work has been used to understand the mechanisms that may contribute to anxiety. The first section introduces behavioral research that has examined attention toward threat, and which has laid a foundation for the ERP investigations that are the focus of the latter part of this chapter. This review of behavioral work is followed by an introduction to ERP components that have proved to be useful in the investigation of attention and biases in attention toward threat. Next, studies of attention toward threat in children are reviewed—these studies use paradigms tailored to participant ability. The end of the chapter focuses on remaining questions surrounding attentional biases toward threat, and the relative strengths of ERP and behavioral measures in addressing these issues.

BEHAVIORAL STUDIES

Attention toward threat has traditionally been measured using visual spatial attention tasks such as the visual search task (Byrne & Eysenck, 1995; Neisser, 1963), the dot-probe task (MacLeod, Mathews, & Tata, 1986) and the Posner cue task (Posner, 1980). In these tasks, attention is thought to be modulated by the salience of threatening and neutral stimuli. That is, participants should be faster to detect threatening stimuli or respond more quickly to targets that replace threatening compared to neutral stimuli. More recently, researchers have used tasks in which participants are *instructed* to attend only to stimuli presented in a certain location (e.g., stimuli that appear horizontally but not vertically; Vuilleumier, Armony, Driver, & Dolan, 2001). In this latter type of task (referred to as “directed attention” tasks, below), researchers examine the contributions of task-directed visuospatial attention and stimulus-driven visuospatial attention on the processing of threatening and neutral stimuli. More details on these tasks and how they have been used to examine attention toward threat are presented below.

VISUAL SEARCH TASK

Visual search tasks require participants to scan an area to locate a specific target (Byrne & Eysenck, 1995; Neisser, 1963). For instance, participants might locate a stimulus of one valence (e.g., a fearful face) within a display filled with images of a different valence (e.g., neutral faces). Behaviorally, faster reaction times on trials containing threatening compared to non-threatening

target stimuli indicate an attentional bias toward threat. Along the same lines, slower response times on trials that contain threatening *distracters* may index biased attention toward threat, insofar as detecting a neutral target among many threatening distracters requires overcoming the tendency to prioritize the processing of the threatening distracters.

For instance, Öhman, Flykt, and Esteves (2001a) found that nonanxious participants were faster to detect threatening images (i.e., snakes or spiders) in an array of non-threatening images (i.e., flowers or mushrooms) than they were to detect non-threatening images in an array of threatening images. In another study, Öhman, Lundqvist, and Esteves (2001b) presented healthy individuals with threatening, friendly, sad, “scheming” (i.e., simultaneously smiling and frowning), and neutral faces during a visual search task. Threatening faces were located fastest compared to other negative faces (i.e., sad and scheming faces), even when distracter faces were emotional. In both studies, threatening stimuli appeared to automatically capture attention and facilitate visual search when they were targets.

There is also evidence that an attentional bias toward threat in the visual search task may be enhanced among anxious participants. Gilboa-Schechtman and colleagues (Gilboa-Schechtman, Foa, & Amir, 1999) presented socially anxious and nonanxious participants with a single emotional (i.e., happy, angry, or disgusted) or neutral face embedded among distracting faces. Both nonanxious and socially anxious participants were faster to respond when an angry face was embedded among happy faces, but socially anxious individuals were especially quick at noticing angry faces. Additionally, socially anxious participants were slower to respond when distracters were angry or happy instead of neutral; nonanxious participants were not distracted by either kind of emotional face, suggesting that social anxiety might be associated with increased interference from emotional faces in general (see also Miltner, Krieschel, Hecht, Trippe, & Weiss, 2004).

Rinck and colleagues (Rinck, Becker, Kellermann, & Roth, 2003, Experiment 1) conducted a similar investigation, using emotional words instead of faces, among participants with generalized anxiety disorder (GAD), speech phobia, and nonanxious controls. On each trial, participants were asked to search for a specific word within a matrix of emotional (i.e., GAD-related, speech-related, happy) or neutral words. GAD participants were distracted by matrices consisting of GAD-related words (as indicated by delayed responses), but showed no advantage in detecting GAD-related words. Participants with speech phobia did not exhibit distraction or enhancement effects. Therefore, in certain kinds of anxiety and task, threatening stimuli might result in increased distraction, but no appreciable gain in detection of these stimuli when they are task relevant.

In sum, research on attention to threat using the visual search task suggests that both nonanxious and anxious individuals are faster to detect threatening compared to neutral or other (e.g., happy) images in their environment. Anxious individuals, however, may have greater difficulty disengaging from threatening stimuli in the visual search task, as evidenced by increased interference from threatening distracters.

DOT-PROBE TASK

A sample trial from the dot-probe task is depicted in Figure 11.1. In the dot-probe paradigm, participants view neutral or emotional stimuli—typically, a pair of faces—one to the left and one to the right of fixation. Alternatively, stimuli can be words (Mathews, Ridgeway, & Williamson, 1996; Mogg et al., 1997) or images (e.g., IAPS pictures), and can be presented above and below fixation (e.g., Kimonis, Frick, Fazekas, & Loney, 2006; Koster, Crombez, Verschueren, & De Houwer, 2004; MacLeod et al., 1986). Stimuli are presented simultaneously for a duration lasting anywhere from 100 ms to 1500 ms. Following picture offset, a visual probe (typically a dot) appears briefly in the location of one of the previous images. Participants are required to respond as quickly as possible by indicating the location of the dot on the screen (e.g., left or right; top or bottom). Alternatively, participants may perform a *target-discrimination* task (see Figure 11.1) in which one of two possible targets has to be categorized (e.g., a pair of horizontally versus vertically

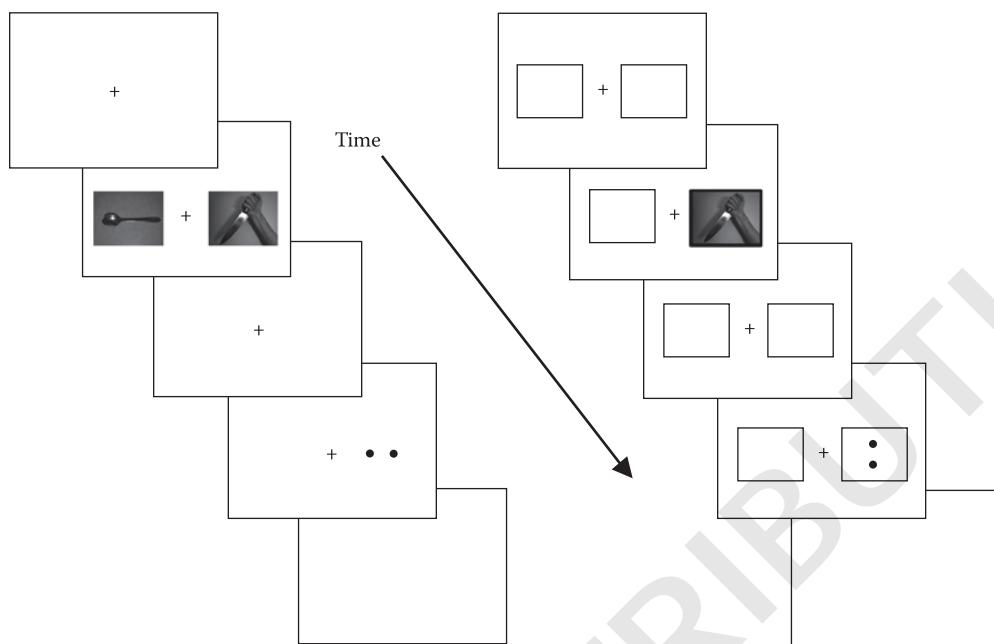


FIGURE 11.1 Dot-probe tasks.

arranged dots). In both versions of the task, faster responses to targets that replace threatening compared to non-threatening stimuli are taken to indicate an attentional bias toward threat. If threatening stimuli capture attention, then reaction time to targets subsequently presented in the same location should be facilitated. Participants may also be more *accurate* in responding to targets that replace threatening stimuli because target discrimination should be easier for targets that appear in spatially attended locations.

If the preferential allocation of attention to threatening stimuli is evolutionarily adaptive, then all individuals should show some bias toward threatening stimuli—even in the absence of clinically significant anxiety. Unlike research using the visual search task, which has found facilitated search for threatening stimuli among nonanxious participants, the majority of studies using the dot-probe task have not found evidence for biased attention toward threat among nonanxious individuals. Generally, healthy participants have comparable reaction times to targets presented in the place of threatening and neutral stimuli (see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007 for a review; cf. Lipp & Derakshan, 2005; Waters, Lipp, & Spence, 2004). One possibility is that more salient stimuli are needed to elicit attentional biases toward threat among nonanxious participants (Mogg et al., 2000). Threatening *words*, such as “knife”, “chase,” or “murder” may not activate fear as effectively as threatening *images* in healthy adults (Mogg & Bradley, 1998). Along the same lines, even some *images* may not be salient enough to bias attention in the dot-probe task: Mogg and colleagues (2000) found that highly threatening images (e.g., mutilated bodies) elicited an attentional bias in both low and high trait-anxious participants, however, mildly threatening images (e.g., soldiers holding guns) did not elicit a bias among low trait-anxious participants. This work suggests that threatening stimuli exist on a continuum, and that anxious individuals might best be distinguished from nonanxious individuals in terms of attention allocated toward mildly threatening stimuli. Outside of the laboratory, this phenomenon might be observed as increased sensitivity toward threatening stimuli on the part of anxious individuals. For example, an anxious individual might perceive even a mildly threatening dog (e.g., a dog that is growling) as threatening, whereas both nonanxious and anxious individuals would probably perceive a truly angry dog (e.g., ears flat against its head, teeth exposed) as threatening.

Another possibility is that healthy individuals initially attend to threatening stimuli, but quickly disengage attention in the absence of a real threat. In order to delineate the time course of attentional biases toward threat, researchers using the dot-probe task have varied the presentation duration of the cues. When presenting stimuli for a relatively short duration (e.g., 100 ms), participants should have less time to shift attention between stimuli; by contrast, when stimuli are presented for longer durations, participants may have time to disengage from threatening stimuli. For example, in a study by Cooper and Langton (2006), participants were presented with threatening and neutral cues for 100 ms or 500 ms. Nonanxious participants exhibited a bias toward threatening stimuli in the dot-probe task when stimuli were presented for 100 ms; at 500 ms, however, they no longer exhibited this bias and instead attended toward neutral stimuli. Similarly, Bradley and colleagues (Bradley, Mogg, White, Groom, & de Bono, 1999) found no evidence of an attentional bias toward threat in healthy control participants when stimuli were presented for 500 ms or 1250 ms. Together, these data suggest that initial biases in attention toward threat in dot-probe tasks may dissipate rapidly among those who are relatively nonanxious.

In contrast to mixed results in nonanxious controls, an attentional bias toward threat has been consistently observed among participants with elevated anxiety (i.e., both clinical and non-clinical) using the dot-probe task (see Bar-Haim et al., 2007 for a review). For example, MacLeod and colleagues (1986) found that anxious individuals were faster to respond to probes replacing threatening compared to non-threatening words; nonanxious participants did not demonstrate this bias. These results have also been found in clinically anxious participants: Bradley, Mogg, White, Groom, and de Bono (1999) demonstrated that individuals with GAD displayed faster reaction times to probes following threatening faces, whereas nonanxious controls did not. Similar results have been found for participants with social anxiety (Asmundson & Stein, 1994) and post-traumatic stress disorder (PTSD; Bryant & Harvey, 1997).

Some work using the dot-probe has supported the notion that anxious individuals may initially engage with, and then subsequently avoid, threatening stimuli (i.e., the vigilance-avoidance hypothesis described above). For example, Mogg and colleagues (2004) found that participants high in trait anxiety were more vigilant for threatening stimuli when cues were presented for 500 ms. When cues were presented for 1500 ms, neither group exhibited an attentional bias toward threatening stimuli. However, a subgroup of participants with blood phobia exhibited significant avoidance of threatening pictures at the longer cue duration.

In sum, there is evidence from the dot-probe paradigm to suggest that although nonanxious individuals may attend preferentially to threatening images, this effect may be relatively short-lived and only evident for brief cue presentation durations. In contrast, an attentional bias toward threatening stimuli is reliably observed in anxious participants using the dot-probe task, even at longer cue durations (e.g., 500 ms), suggesting that a failure to disengage from threatening stimuli may characterize anxious individuals (Fox, 2004; Fox et al., 2001). In other studies, initial attention toward threatening stimuli appears to be followed by subsequent avoidance of these stimuli in anxious individuals (Mogg et al., 2004). Therefore, whether or not anxiety is associated with difficulty disengaging from threatening stimuli, a vigilant avoidant pattern of attention toward threat, or a more complex pattern of attention, is yet to be fully determined.

POSNER CUE TASK

The dot-probe task has been criticized for not being able to effectively disambiguate biases *toward* threat versus disengagement *from* threat (e.g., Fox et al., 2001, 2002; Georgiou et al., 2005; Yiend & Mathews, 2001). As noted above, cues are typically presented for a relatively long duration (e.g., 500 ms), meaning that participants have time to attend to more than one stimulus before the onset of the target. Faster reaction times on trials in which targets replace threatening stimuli might therefore be due to differences in initial engagement of attention, or subsequent failures to disengage attention from threat—or both processes. Although presenting stimuli for shorter durations (e.g., 100 ms)

might help ensure that participants do not have time to attend to more than one stimulus (see Cooper & Langton, 2006)—and therefore might capture initial engagement *with* threat rather than a failure to disengage—presenting stimuli for longer durations might confound these two processes.

One potential solution is to use the Posner cue task (Posner, 1980); a sample trial from the Posner cue task is depicted in Figure 11.1 (right). Instead of displaying two cues, participants view a single cue—presented either to the left or to the right of fixation, for instance. Following cue offset, targets appear where the cue was presented (a *valid trial*) or in the opposite location (an *invalid trial*). Because there is only one cue, it is assumed that participants' attention is captured by this stimulus. Thus, any subsequent differences in reaction time for targets that appear *opposite* to threatening compared to neutral cues (i.e., invalid threatening compared to invalid neutral trials) is taken to indicate difficulty disengaging from the cue. Slower reaction times for these trials suggests greater 'dwell time' on threatening cues (Fox, 2004; Fox et al., 2001, 2002).

To investigate the presence of an attentional bias toward threat in nonanxious participants using the Posner cue task, Fox, Russo, and Dutton (2002) presented low trait-anxious individuals with angry, happy, and neutral facial cues. As expected, low trait-anxious participants were faster to categorize targets on valid trials; however, the type of cue did not impact categorization time on invalid trials—there was no evidence for increased dwell time among the low-anxious individuals. By the same token, high trait-anxious individuals were slower to respond on invalid trials with threatening compared to neutral cues. Amir and colleagues (2003) also used the Posner cue task and found that disengagement from socially threatening words distinguished socially anxious participants from healthy participants (see also Yiend & Mathews, 2001). These data are consistent with work using the dot-probe task insofar as only anxious individuals demonstrate biased attention toward threatening stimuli in terms of increased dwell time to invalid threat cues (other studies have found similar results; Georgiou et al., 2005).

DIRECTED ATTENTION TASKS

If threatening stimuli preferentially capture attention, they might even do so even when participants are explicitly told to ignore these stimuli and to attend to other stimuli that are presented simultaneously in other locations onscreen. For example, Vuilleumier and colleagues (2001) instructed nonanxious participants to make a same versus different discrimination among pairs of task-relevant stimuli while task-irrelevant stimuli (houses, fearful faces, or neutral faces) were presented in other locations. Same/different judgments of the task-relevant stimuli were made more slowly in the presence of fearful than neutral task-irrelevant stimuli. The emotional valence of the task-relevant stimuli, meanwhile, did not influence reaction time. These results suggest that despite focused attention on task-relevant stimuli, task-irrelevant threatening stimuli continue to receive preferential processing that can compromise task performance. Directed attention tasks of this type might be thought of as variants of the dot-probe task, where the cues are actually relevant to the task; like the dot-probe however, the threatening or neutral nature of the stimuli are still irrelevant to the task.

Investigations using directed attention tasks have consistently found that fearful stimuli are distracting and result in increased reaction times and error rates in nonanxious samples (Bishop, Duncan, & Lawrence, 2004; Keil, Moratti, Sabatinelli, Bradley, & Lang, 2005; MacNamara & Hajcak, 2009, 2010). For example, MacNamara and Hajcak (2009) investigated the effect of task-irrelevant stimuli on performance as a function of individual differences in state anxiety. Participants were presented with four IAPS pictures simultaneously on each trial, and were instructed to attend to either the horizontal or vertical pairs of stimuli. Across participants, response times to task-relevant stimuli were slower when distracting stimuli were threatening compared to neutral; error rate was also higher for trials containing threatening distracters. The extent to which threatening stimuli interfered with performance, however, was not greater for participants with higher levels of self-reported state anxiety (MacNamara & Hajcak, 2009). Nonetheless, in a follow-up study that used the same task, *clinically* anxious participants—who may allocate greater attention toward

threatening stimuli—were differentiated from nonanxious controls by increased behavioral interference from threatening stimuli (MacNamara & Hajcak, 2010).

SUMMARY

There is evidence across a variety of tasks to suggest that anxious individuals attend selectively to threatening stimuli. Moreover, anxious individuals may initially orient toward threatening stimuli *and* subsequently have difficulty disengaging from threatening stimuli. Attentional biases toward threat have been found in individuals with PTSD (Buckley, Blanchard, & Neill, 2000; Pineles, Shipherd, Welch, & Yovel, 2007), GAD (Bradley et al., 1999; MacNamara & Hajcak, 2010), and social anxiety (Amir et al., 2003). Such biases have also been found among individuals high in state anxiety (Fox et al., 2001) and in children of anxiety-disordered parents (Pine et al., 2005). A recent meta-analysis (Bar-Haim et al., 2007) calculated an effect size of $d = 0.45$ across 172 studies of threat-related attentional biases in a variety of anxiety disorders, as well as in individuals with high trait anxiety. Thus, attentional biases do not seem to be specific to certain anxiety disorders, but might be a feature of elevated anxiety more generally.

These results have important clinical implications—for instance, several studies have demonstrated that maladaptive attentional biases toward threat increase symptoms of anxiety (e.g., Bögels & Mansell, 2004; Mogg & Bradley, 1999). Mathews, Mogg, Kentish, and Eysenck (1995) found that adult following treatment, participants with GAD no longer differed from healthy controls with regard to interference from task-irrelevant threatening words when searching for target words located in another area of the screen. Thus, attentional bias scores might provide a useful outcome measure of cognitive changes associated with treatment, at least in adults.

As reviewed above, healthy individuals are characterized by an attentional bias toward threat using visual search and directed attention tasks, but not the dot-probe task (Bar-Haim et al., 2007). The dot-probe task is one of the most widely used tasks for measuring attention toward threatening stimuli, yet two recent studies suggest that the dot-probe task may have poor psychometric properties (i.e., reliability) in nonanxious populations (Schmukle, 2005; Staugaard, 2009). The absence of an attentional bias toward threat in studies that have used the dot-probe task is somewhat troubling—especially since other tasks suggest that nonanxious individuals prioritize threatening stimuli. One wonders whether the dot-probe task measures attentional bias to threat, or processes specific to anxiety *disorders*.

There are many potential explanations for why nonanxious participants are not characterized by an attentional bias toward threat in the dot-probe task. As described earlier, the stimulus timing is often long enough that initial allocation of attention to threat could be followed by disengagement: Behavioral responses to targets can only index where attention is allocated at the time the target is presented. Moreover, behavioral measures provide an endpoint assessment of many processes that intervene between the occurrence of the stimulus and the execution of the response. Thus, behavioral measures may index the combined effect of threatening stimuli on motor response and other processes, rather than just selective attention. In line with this notion, several studies suggest that processing threatening stimuli may slow subsequent reaction times. For example, participants are slower to categorize centrally presented targets presented after emotional compared to neutral IAPS pictures (Mitchell, Richell, Leonard, & Blair, 2006; Weinberg & Hajcak, under review). In the dot-probe task, then, threatening stimuli might prompt shifts of spatial attention, which could facilitate the detection of targets subsequently presented in the same location; at the same time, however, attention toward threatening stimuli might interfere with reaction time, possibly as part of an orienting or defensive reflex (i.e., “freezing”; Koster et al., 2004). The absence of a behavioral effect, then, could be due to the combined influence of threat-related attentional cuing on the one hand, and threat-related response slowing, on the other hand (see also Mogg, Holmes, Garner, & Bradley, 2008).

Finally, participants may be able to compensate for the effect of attentional biases on behavior in various ways. For example, participants can adopt a particularly cautious response strategy:

behavioral biases may not be evident if participants respond very slowly on *all* trials. These limitations in behavioral measures apply to nonanxious individuals, and to comparisons between healthy control participants and patient populations (i.e., the failure to observe an attentional bias toward threat in control participants may be due to poor measurement specificity).

USING ERPS TO STUDY ATTENTION TOWARD THREAT

More recently, researchers have begun to incorporate ERPs in the study of attentional bias toward threatening stimuli. ERPs can index attention toward threat even when attentional allocation does not impact the timing or choice in behavior, such as when participants may have learned to compensate for attentional biases. Because ERPs can be measured using tasks that do not require overt responses, they are also useful in evaluating attentional biases when participants are unable to easily execute motor movements (e.g., infants). Moreover, ERPs have excellent temporal resolution, and provide a direct, millisecond-by-millisecond measure of neural activity (for a general overview on ERPs, see Kappenman & Luck, *in press*; Luck, 2005). Thus, ERPs can provide an assessment of the point of initial allocation of attention, as well as any subsequent shifts of attention, because they can be measured at a wide variety of time points after—or even before—stimulus presentation. ERPs therefore provide a means to determine the stage or stages of processing that support behavioral effects.

ERPs have been used to study attention-related processing for decades. In fact, it is in the field of attention that ERPs first gained widespread acceptance for their usefulness in answering questions about processing that other techniques, including behavioral and other neuroimaging techniques, leave unanswered. Specifically, ERPs were used to resolve a longstanding debate in the attention literature about whether attention operates at an early stage of processing (i.e., during perceptual stages) or a late stage of processing (i.e., during postperceptual stages; see review in Luck & Kappenman, *in press*). ERPs are particularly applicable to the study of attention, because in addition to assessing the processing of attended stimuli, ERPs can index neural response to unattended stimuli. By contrast, it is difficult to assess the processing of unattended stimuli with behavioral measures, because asking participants to make a behavioral response to an unattended stimulus would likely induce a shift of attention to those stimuli. Despite having been used extensively to examine attentional processes in non-emotional contexts (i.e., in the cognitive literature), ERPs have been relatively underutilized in studying attentional biases *toward threat*. A description follows of ERP components that are most appropriate for assessing attentional bias to threat, after which there is a review of some studies that have used ERPs in this manner.

ERP COMPONENTS FOR ASSESSING ATTENTION TOWARD THREAT

Attention modulates the activity of a broad range of cognitive systems, including perceptual systems, motor systems, and memory systems—and attentional processing has been shown to influence a wide array of ERP components. Here the discussion is limited to the P1 wave, the N2pc, the P300 and the late positive potential (LPP) because they are particularly useful for indexing attention toward threatening stimuli.

The P1 wave begins around 70 to 100 ms after the onset of a visual stimulus and appears maximal over lateral occipital electrode sites. The P1 seems to index early, feed-forward sensory activity in extrastriate areas of the visual cortex that is modulated by top-down processes (Hillyard, Vogel, & Luck, 1998). The widely replicated and pervasive P1 attention effect involves a larger (more positive) P1 wave for stimuli presented at an attended location relative to stimuli presented at an unattended location, and it is sometimes accompanied by an N1 attention effect (for reviews, see Hillyard et al., 1998; Mangun, 1995). Attention effects (see Figure 11.2) have been demonstrated in a range of paradigms, including the dot-probe task (e.g., MacLeod et al., 1986; Mogg & Bradley, 1999) and Posner cue task (Eimer, 1994a, 1994b; Hopfinger & Mangun, 1998; Luck et al., 1994; Mangun & Hillyard, 1991) described earlier in this chapter.

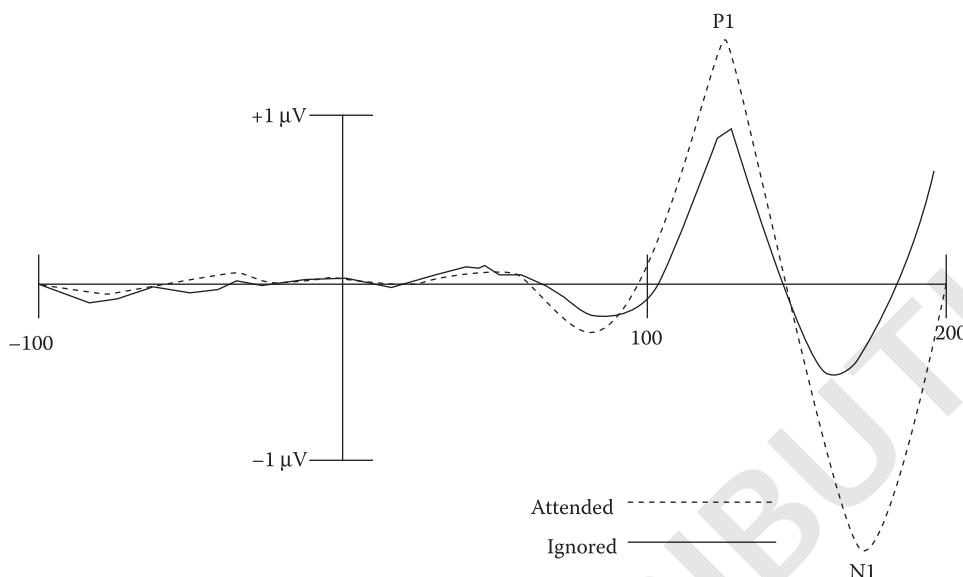


FIGURE 11.2 P1 and N1 for attended stimuli.

In the dot-probe task, the P1 measured in response to the probe is larger to targets presented at attended locations compared to targets presented at unattended locations. For the Posner cuing paradigm, the P1 is larger for valid targets compared to invalid targets (i.e., targets that are presented in place of cues compared to opposite the cue location). When the P1 wave is compared between targets presented at valid compared to invalid locations, one can assess whether attention was directed toward the cued or uncued location when the target was presented. Therefore, these ERP components easily complement the behavioral measures in commonly used task designs in the study of attentional bias toward threatening stimuli. Importantly, the P1 response to targets can be measured in cases in which no behavioral response is made and can therefore capture effects too small to elicit measurable behavioral differences.

Another ERP component that has been studied extensively in the attention literature is the N2pc, which reflects the focusing of attention on a potential target item in a display (for a review, see Luck, *in press*). The N2pc (*N2-posterior-contralateral*) consists of a greater negativity at posterior electrode sites over visual cortex contralateral to an attended location compared with electrode sites ipsilateral to an attended location. An example of the N2pc is shown in Figure 11.3. It occurs approximately 200 to 300 ms after stimulus presentation and is typically largest at electrode sites over occipito-temporal cortex. The contralaterality of the N2pc requires the presentation of stimuli at lateralized locations in the display. Moreover, the N2pc is typically only observed in tasks in which a target item is surrounded by distracter items, thus requiring attention to locate the target item (for a detailed discussion of factors important in the design of attention experiments using ERPs, see Kappenman & Luck, *in press*). In fact, the size of the N2pc varies as function of the number and location of distracter items in the display (see Luck, *in press* for a review), and it is generally thought to reflect both the focusing of visuospatial attention on a potential target item and the filtering of the surrounding distracters. Therefore, the tasks typically used to study attentional bias, including the dot-probe paradigm and the visual search task, discussed in the present chapter, are ideal paradigms for examining the N2pc.

As discussed earlier, the excellent temporal resolution of ERPs provides a means of examining the time course of information processing stages. This is especially true in the context of the N2pc, in which the onset time of the N2pc provides a precise measure of the time it takes the brain to determine where to allocate visuospatial attention. For example, the onset time of the N2pc depends

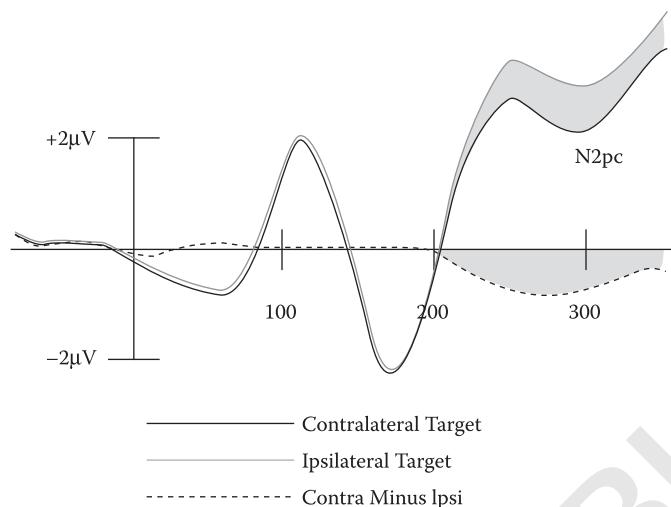


FIGURE 11.3 The N2pc, as assessed with lateralized stimulus arrays.

on the salience of the target item, with more salient items (such as “popouts” in a visual search task) resulting in an earlier onset N2pc compared to less salient items (for a review, see Hopf et al., 2000, 2006; Hopf, Boelmans, Schoenfeld, Luck, & Heinze, 2004; Luck, in press). Therefore, the N2pc can be used to assess the time course of the allocation of attention. It is important to note that this timing reflects an *upper bound*. For example, the N2pc could be used to determine that attention was allocated a threatening stimulus *by* 200 ms, but not that attention was *not* allocated to a threatening stimulus *until* 200 ms.

Studies that have examined the N2pc and its magnetoencephalographic equivalent, termed the M2pc, suggest that they are generated in the lateral occipito-temporal cortex (consistent with the scalp distribution of the N2pc), with generators in high-levels of the ventral visual processing pathway (for details, see Hopf, et al., 2000, 2004, 2006). Thus, the N2pc is a measure of the neural processing related to focusing attention in visual cortex.

One of the most researched ERP components is the P300, a parietally maximal positivity that peaks approximately 300 to 400 ms after stimulus presentation. The P300 was first identified in the context of cognitive (i.e., non-affective) paradigms: it was larger for target compared to non-target stimuli (Johnson, 1984, 1986), and for unexpected stimuli (Duncan-Johnson & Donchin, 1977; Squires, Donchin, Herning, & McCarthy, 1977). However, the P300 is also larger for emotional compared to non-emotional stimuli (Johnston, Miller, & Burleson, 1986; Keil et al., 2002; Lifshitz, 1966; Mini, Palomba, Angrilli, & Bravi, 1996; Naumann, Bartussek, Diedrich, & Laufer, 1992). Thus, it seems to index attention to motivationally relevant stimuli, whose importance may be denoted in a top-down (i.e., for target stimuli) *or* in a bottom-up (i.e., emotional content) manner. When unexpected or motivationally salient stimuli appear in the environment, an organism may need to change its mental model of the environment to respond appropriately; it has been suggested that the P300 is a neural signature of a context updating mechanism (Polich, 2003). A recent review of the literature suggested that the P300 might arise from the parietal cortex and cingulate and that visual stimuli elicit modality specific contributions from the inferior temporal and superior parietal cortex (Linden, 2005). As far as neurochemical substrates of the P300 are concerned, it has been suggested that the P300 might reflect neuromodulatory activity of the locus coeruleus norepinephrine system (Nieuwenhuis, Aston-Jones, & Cohen, 2005).

Contemporary research in emotion has focused on a P300-like ERP referred to as the late positive potential (LPP; see Figure 11.4). Modulation of the LPP by emotional stimuli begins in the time range of the P300, and is sustained for the entirety of stimulus presentation (e.g., up to six seconds,

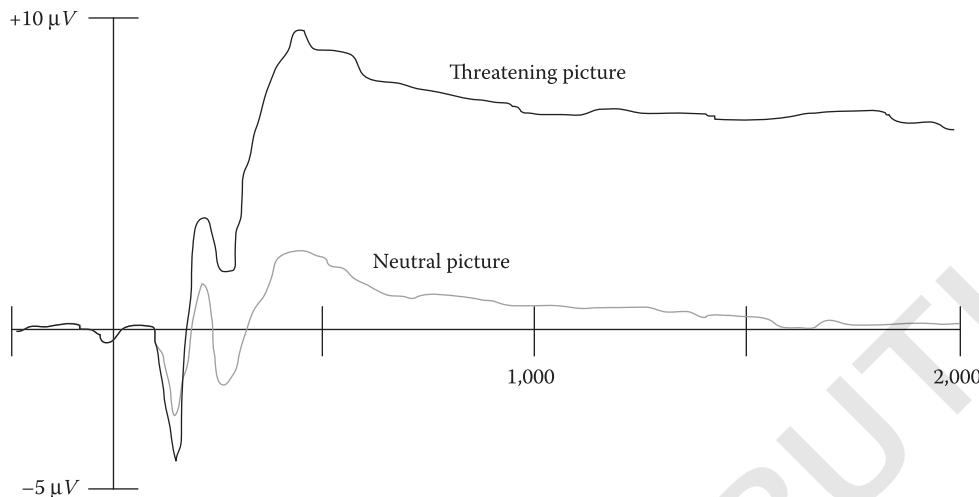


FIGURE 11.4 A depiction of the LPP elicited by threatening pictures (black line) and neutral pictures (gray line).

Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Dillon, Cooper, Grent-‘t-Jong, Woldoff, & LaBar, 2006; Pastor et al., 2008; Schupp, Junghöfer, Weike, & Hamm, 2003) and

even beyond stimulus offset (Hajcak & Olvet, 2008). Thus, unlike the relatively transient P300, the LPP is evident as a sustained positivity following the presentation of emotional compared to neutral stimuli. Whether the P300 and LPP are the ‘same’ component is an interesting question. Recent work using principal components analysis suggested that the LPP might be more accurately described as a series of several overlapping positivities that emerge from approximately 300 to 600 ms after stimulus onset at parietal sites; 800 to 1000 ms after stimulus onset at occipital, parietal and central sites and at approximately 1600 ms after picture onset at frontal sites (Foti, Hajcak, & Dien, 2009). Thus, the earlier portion of the LPP might be the P300. However, the later portion of the LPP is more widely distributed across the scalp, and is evident more centrally and even somewhat frontally (Foti et al., 2009; Foti & Hajcak, 2008; Hajcak, Dunning, & Foti, 2007; MacNamara, Foti, & Hajcak, 2009).

For the duration of the paper, we do not distinguish between the P300 and LPP—we simply refer to the sustained positivity evident following emotional compared to neutral stimuli as the LPP. Source localization suggests that the LPP originates in areas of the visual cortex: Keil and colleagues identified generators in the occipital and posterior parietal cortex (Keil et al., 2002). Similarly, research that combined ERP and fMRI methods found that the LPP correlated with BOLD signal in secondary visual areas in occipital, inferior temporal, and parietal regions (Sabatinelli, Lang, Keil, & Bradley, 2007). Finally, although direct contributions from the amygdala to the LPP have not been identified, it has been suggested that the amygdala might contribute to the LPP via re-entrant projections to the visual cortex (Lang & Bradley, 2010).

The LPP is believed to index the elaborated processing of salient visual stimuli (Schupp, Flaisch, Stockburger, & Junghöfer, 2006) and has been associated with better memory for pictures (Dolcos & Cabeza, 2002). The LPP is also sensitive to changes in stimulus *meaning*—for example, negatively compared to neutrally described IAPS pictures, rated as more unpleasant and more emotionally arousing, elicit larger LPPs (Foti & Hajcak, 2008; MacNamara et al., 2009; MacNamara, Ochsner, & Hajcak, in press). The LPP is smaller when participants are asked to reduce the intensity of their emotional response to pictures (Hajcak, Moser, & Simons, 2006; Moser, Hajcak, Bukay, & Simons, 2006), suggesting that it is sensitive to internally generated changes in stimulus meaning. Finally, the LPP is also reduced when participants are asked to attend to non-arousing compared to arousing

picture regions (e.g., Dunning & Hajcak, 2009; Hajcak, Dunning, & Foti, 2009). Thus, the LPP is sensitive both to the emotional salience of pictures and to the attention participants allocate toward the emotional nature of pictures. Moreover, emotional modulation of the LPP—unlike some earlier ERP components—is relatively independent of the physical properties of stimuli (e.g., picture complexity; Bradley, Hamby, Löw, & Lang, 2007). As such, the LPP provides a sensitive index of the dynamic processing of motivationally salient stimuli.

There are many potential benefits to using ERPs to index attention toward threat in both normative and pathological samples; nevertheless, the majority of research on attentional biases to date has been behavioral. We now review research that has used ERPs—alone or in conjunction with behavioral measures—to examine attentional biases toward threat, with a focus on tasks that have traditionally been used in the behavioral literature and adapted for use with ERPs.

ERP STUDIES

VISUAL SEARCH TASK

Few emotion researchers have used the visual search paradigm with ERPs, and it has not always been employed to index attention toward threatening stimuli (e.g., Tang, Li, Wang, & Zhu, 2009). In one study, Flykt and Caldara (2006) recorded reaction time, heartrate and ERPs while snake-phobic, spider-phobic and non-phobic participants searched arrays of neutral pictures (e.g., flowers) for pictures of feared stimuli (e.g., snakes), threatening but phobia-irrelevant stimuli (e.g., spiders), or neutral stimuli (e.g., mushrooms). Phobic participants exhibited larger LPPs and faster reaction times to feared compared to non-feared and neutral stimuli. Heartrate and earlier ERP components (i.e., the P1 elicited by search targets) did not differ across groups. Therefore, among phobic participants, feared compared to non-feared stimuli seem to elicit greater attentional engagement and performance on these trials is similarly facilitated. Interestingly, phobic individuals may be distinguished from nonanxious controls by increased later and more elaborative processing of feared stimuli (i.e., as indexed by the LPP) rather than by increased early processing of these stimuli (i.e., the P1).

DOT-PROBE TASK

ERPs used to index attention in the dot-probe task can be time-locked to cues (“cue-locked”) or time-locked to targets that are presented in place of cues (“target-locked”). Many ERP studies that have used the dot-probe task have examined both these types of component. For instance, the P1 component can be measured in response to targets that replace cues in the dot-probe task. Furthermore, because stimuli in the dot-probe task are frequently presented to the left and right of fixation, contralateral components such as the N2pc, are ideal for measuring biases in cue-locked visual selective attention.

Several ERP studies using the dot-probe task have included both pleasant and threat-related stimuli, in order to differentiate attentional biases toward threatening stimuli in particular from biases toward emotional stimuli in general. Some of these studies have found that pleasant stimuli may also bias attention. For example, Brosch and colleagues (Brosch, Sander, Pourtois, & Scherer, 2008) found that targets presented in the location of both pleasant stimuli (i.e., baby faces) and threat-related stimuli (i.e., angry faces) elicited larger P1s compared to those that replaced neutral stimuli (reaction time was also faster for targets that replaced both pleasant and threat-related compared to neutral stimuli). These results suggested that threatening stimuli do not receive prioritized processing compared to pleasant stimuli, and that *emotional* salience might determine attentional allocation. In a study by Holmes, Bradley, Nielsen and Mogg (2008), behavioral results suggested a similar pattern: Participants responded faster to targets that replaced angry and happy

compared to neutral faces. However, the ERP results indicated that angry but not happy faces modulated the *early* N2pc, whereas both happy and angry faces modulated later onset ERPs. Therefore, when both pleasant and threatening stimuli capture attention, threatening stimuli seem to modulate attention *earlier* than pleasant stimuli. This study is an illustrative example where ERP results can provide a more nuanced view of the time course of attentional bias toward threat.

Not all data are consistent with the notion that pleasant stimuli bias attention. For instance, Pourtois and colleagues (Pourtois, Grandjean, Sander, & Vuilleumier, 2004) found that only targets that replaced upright fearful faces (and not inverted fearful, upright happy or inverted happy faces) elicited increased P1s and faster reaction times. In addition, participants were better at discriminating targets that replaced fearful faces. Pourtois and colleagues (2004) also found that fearful compared to happy faces elicited increased C1 amplitudes. The C1 is an ERP component occurring approximately 90 ms following stimulus onset, and reflects activity in the primary visual cortex (Clark, Fan, & Hillyard, 1994). After source localizing the P1 and C1 components to the extrastriate and striate areas, respectively, it was concluded that activity in the primary visual cortex might be modulated by threatening stimuli very early on (< 100ms), and that visual attention (as indexed by the P1) might be biased to targets that subsequently appear in the same location. These results were not found for happy faces.

Work by Fox and colleagues (Fox, Derakshan, & Shoker, 2008) also suggested that pleasant stimuli do not receive prioritized processing in the dot-probe task, and further suggested that threatening stimuli are particularly salient for anxious individuals. Using pairs of angry-neutral and happy-neutral faces in a dot-probe task, Fox and colleagues found that neither participants who were low in anxiety, nor participants who were high in anxiety showed an N2pc for happy faces. However, compared to participants who were low in anxiety, participants high in anxiety exhibited an increased early N2pc to angry faces. For targets that appeared in place of angry faces at short latencies (i.e., 150 ms after picture offset), the P1 amplitude was also increased, and this effect was not modulated by trait anxiety. Therefore, the N2pc and P1 results suggest that threatening, but not pleasant stimuli, direct spatial attention—and that anxiety is related to a further increase in this attention during cue processing.

POSNER CUE TASK

Li and colleagues (Li, Li, & Luo, 2005) used a modified version of the Posner cue paradigm in which cues were IAPS pictures rather than faces. Only participants who were high in trait anxiety were faster to respond on trials in which threatening compared to neutral cues predicted the location of the target; participants who were low in trait anxiety did not show this bias. The ERP results followed a similar pattern: Participants who were high in anxiety had larger P1 amplitudes for targets that appeared in place of threatening compared to neutral pictures; by contrast, participants low in anxiety had *smaller* P1 amplitudes for targets that appeared in place of threatening compared to non-threatening cues, suggesting that nonanxious individuals may rapidly avoid uninformative threat cues.

In nonanxious populations, ERP work using the dot-probe and Posner cue tasks suggests that threat-related stimuli are afforded special status compared to other emotionally salient (i.e., pleasant) stimuli (Fox et al., 2008; Holmes et al., 2008; Pourtois et al., 2004; Santesso et al., 2008)—in particular, threat appears to capture attention *earlier* than pleasant stimuli. Some work even suggests that compared to happy stimuli, neutral stimuli may elicit increased attention because they are perceived as *relatively* more threatening or ambiguous (Santesso et al., 2008). ERP work in anxious participants suggests that these individuals allocate even greater attention toward threatening stimuli than nonanxious individuals, though this work has not provided conclusive evidence as to the specific attentional *patterns* underlying attention toward threat in anxiety (e.g., vigilance avoidance; difficulty disengaging from threatening stimuli).

DIRECTED ATTENTION TASKS

Another means of investigating whether threatening stimuli receive prioritized processing is to determine whether they consume attentional resources even when participants are instructed to attend to a particular spatial location and to ignore threatening stimuli presented in another location. For instance, Carretié and colleagues (2009) required participants to perform a digit categorization task while ignoring moving or static pictures that were either threatening (a spider or a cockroach) or neutral (a ladybird or a butterfly) and were presented in the bottom half of the screen. Participants—who had reported a moderate fear of spiders and cockroaches—were instructed to perform the digit categorization task as quickly and as accurately as possible, while ignoring the distracter stimuli. Trials with moving *threatening* distracters elicited the largest P1 amplitudes and the longest reaction times, suggesting an early attentional bias toward ecologically valid threatening stimuli. Moreover, P1 amplitudes were significantly correlated with reaction time, indicating that the increase in early attentional resources relates to subsequent behavioral interference.

In more difficult tasks, however, attentional resources may not be available for the processing of task-irrelevant threatening stimuli. For example, participants in a study by Eimer and Kiss (2007) were instructed to ignore distracting faces while responding to luminance changes that occurred in a centrally presented fixation cross. Faces were presented to the left, right, above and below fixation and could be either fearful or neutral. Results showed that compared to neutral faces, fearful faces elicited a larger N2pc on trials *without* luminance changes. Therefore, fearful faces seemed to elicit greater attention than neutral faces primarily when concurrent cognitive demands (i.e., target processing) were low. Moreover, there was no effect of face type on performance, suggesting that ERPs provided a particularly sensitive index of attention toward threatening stimuli in this task.

As already suggested, difficult tasks may gate attention toward threatening stimuli presented in unattended locations. However, a good deal of work suggests that this gating of attention is not complete—and that threatening stimuli presented in unattended locations may be processed. For example, in a study by Holmes and colleagues (Holmes, Kiss, & Eimer, 2006), participants performed a demanding task in which they were required to attend either to centrally presented fearful or neutral faces, or to peripherally presented lines. When faces were presented in spatially attended locations, fearful compared to neutral faces elicited an increased LPP. When faces were presented in spatially unattended locations, fearful faces elicited increased positivities early on during stimulus processing (around 200 ms). *Later* onset ERPs (the LPP), however, were not increased for task-irrelevant fearful compared to neutral faces, and reaction times for the lines task were not affected by task-irrelevant faces. Therefore, task-irrelevant threatening stimuli may bias attention may prior to, but not after, approximately 200 ms following stimulus presentation—at least as indexed by ERPs in this task. These findings suggest that cognitive control mechanisms associated with task-directed attention may be slower to exert influence over stimulus processing than stimulus-driven attentional mechanisms.

In line with the results of Holmes and colleagues (2006), MacNamara and Hajcak (2009) also found that threatening stimuli presented in unattended locations did not elicit increased measures of later processing and attention, as indexed by the LPP. In this study, participants viewed pairs of threatening and neutral IAPS pictures presented at task-relevant and task-irrelevant locations. Participants were required to indicate whether images at “target” (i.e., task-relevant) locations were identical or different. Threatening IAPS images elicited increased LPPs only when presented in spatially attended locations (see also Holmes, Vuilleumier, & Eimer, 2003). These results support the notion that among nonanxious participants, later onset ERPs to threatening stimuli are highly subject to manipulations of spatial attention (see also Dunning & Hajcak, 2009; Hajcak et al., 2009). Nevertheless, trials containing threatening stimuli in spatially unattended locations did result in more errors and longer reaction times compared to those containing neutral images. Therefore, although unattended threatening stimuli were not associated with elaborated processing indexed by the LPP, they appear to have attracted sufficient attention to interfere with behavioral response.

Future work may wish to use similar paradigms to examine earlier onset ERP components to determine whether these might account for behavioral interference from threatening distracters. What is clear from the present results, however, is that the increased elaborated processing of threatening stimuli indexed by ERPs such as the LPP—normally observed when participants are instructed to simply view pictures—is not obligatory, and is subject to manipulations of spatial attention.

In addition to these within-group results, MacNamara and Hajcak (2009) also found that increased anxiety was associated with larger LPPs to threatening compared to neutral images presented in task-relevant locations, although there were no associations between anxiety levels and behavioral measures. In a follow-up study that used the same task with clinically anxious individuals (i.e., individuals with GAD) and nonanxious controls, MacNamara and Hajcak found that both the LPP elicited by threatening target stimuli and behavioral interference from threatening distracters distinguished anxious individuals from controls, suggesting that clinical anxiety may be associated with more pervasive attentional biases toward threat in this task.

In line with MacNamara and Hajcak (2009), Buodo, Sarlo and Munafò (2009) found that ERP, but not behavioral measures, distinguished anxious from nonanxious participants. In their study, blood-phobic and nonanxious participants performed a luminance-change detection task (see also Eimer & Kiss, 2007), and used phobia-specific (i.e., injury pictures), threatening but phobia-irrelevant (i.e., attack pictures) or neutral pictures. In this study, control participants evinced larger early N2pc scores for all threatening (i.e., injury and attack) pictures compared to neutral pictures on trials *without* luminance changes, suggesting that threatening stimuli capture attention preferentially on trials with low task demands (i.e., in the absence of targets). Moreover, for control participants, N2pc contralaterality scores were equivalent for injury-neutral and attack-neutral pairs, suggesting that control participants did not allocate greater attention to any particular *kind* of threatening picture. Like the controls, phobic participants also exhibited larger N2pc scores for threatening compared to neutral stimuli, however their contralaterality scores were increased for injury-neutral compared to attack-neutral stimuli pairs. Therefore, for phobic participants, phobia-relevant stimuli may capture attention more effectively than threatening, yet phobia-irrelevant stimuli. In addition, an early N2pc was observed to injury pictures paired with attack pictures—but only among phobic participants (control participants did not seem to distinguish these two picture types in terms of the N2pc). There were no group effects on reaction time or accuracy. Therefore, phobic individuals may be characterized by an early attentional bias for phobia-relevant stimuli that nonetheless does not affect behavior, at least on this task.

SUMMARY

Across a variety of tasks, studies that have examined visual spatial attention using ERPs suggest that an attentional bias toward threat exists among nonanxious participants, and that this bias is further increased among anxious participants. In particular, when the visual search paradigm has been used, both ERP and behavioral results suggest the presence of a bias toward threat that is exaggerated in anxious individuals (e.g., Flykt & Caldara, 2006; Öhman et al., 2001a). Likewise, ERP and behavioral results from directed attention studies generally concur that an attentional bias toward threat exists in nonanxious controls (e.g., Carretié et al., 2009; MacNamara & Hajcak, 2009, 2010; Vuilleumier et al., 2001). However, although threatening stimuli presented in unattended locations might receive increased initial processing, as is evident in early ERPs (Carretié et al., 2009; Holmes et al., 2006), they may fail to elicit later, more sustained processing (Holmes et al., 2006; MacNamara & Hajcak, 2009, 2010). These results may vary, however, depending on task difficulty—if a task is difficult enough, attentional resources may be fully consumed by the task at hand, and insufficient resources may remain for the processing of threatening distracters (e.g., Pessoa, Padmala, & Morland, 2005).

In contrast to studies that have employed visual search and directed attention tasks, studies using the dot-probe task have yielded conflicting ERP and behavioral results. Specifically, ERP studies

suggest evidence of an attentional bias toward threat among nonanxious participants using the dot-probe task, whereas behavioral studies do not (Bar-Haim et al., 2007). As noted earlier, there are many advantages of using ERPs to index attention toward threatening stimuli (e.g., visuospatial attention can be measured *directly*) that may explain why ERPs provide a more sensitive index of attention toward threat, using this task.

Regardless of whether ERP and behavioral results coincide, ERPs can inform the interpretation of behavioral results because ERPs are evident in the pre-response period and are not dependent on response-related processes. For example, ERPs have shed light on the time course of the processing of threatening compared to pleasant stimuli (Holmes et al., 2008), suggest mechanisms by which threatening stimuli may bias visual attention (Pourtois et al., 2004), and have revealed effects of anxiety on attentional biases that were not evident behaviorally (e.g., Buodo, Sarlo, & Munafò, 2009; Fox et al., 2008; MacNamara & Hajcak, 2009; Mueller et al., 2008).

ATTENTION TOWARD THREAT IN CHILDREN

Compared to the literature on attentional biases toward threat in adults, there have been few such studies in children (Bar-Haim et al., 2007; Ladouceur et al., 2009). Determining whether attentional biases toward threat exist in children, however, may be important for understanding whether humans are predisposed to attend toward threatening stimuli, even from a very young age. Moreover, the median age of onset for anxiety disorders may be earlier than that of other disorders (i.e., 11 years of age, Kessler, Berglund, Demler, Jin, & Walters, 2005), and anxiety disorders that onset in adolescence may often persist into adulthood (e.g., Pine, Cohen, Gurley, Brook, & Ma, 1998).

BEHAVIORAL STUDIES

Given infants' limited language comprehension and motor ability, studies with this population tend to employ passive viewing paradigms and infer attentional allocation from looking time measures. In particular, several studies have used a visual paired comparison (VPC) task, which entails presenting two images side by side and monitoring looking time at each image. Peltola and colleagues (Peltola, Leppänen, Maki, & Hietanen, 2009) used a VPC task with happy and fearful faces for a presentation duration of 10 seconds, and found that 7-month-olds, but not 5-month-olds, demonstrated a bias toward fearful faces. This suggests that an attentional bias toward fearful faces begins developing in healthy children between 5 and 7 months of age.

Some work has suggested that biases toward *direct* depictions of threat (i.e., angry faces) may take longer to develop than biases toward *indirect* depictions of threat (i.e., fearful faces). For example, Grossmann and colleagues (Grossmann, Striano, & Friederici, 2007) found no evidence of an attentional bias toward angry compared to happy faces among 7-month-olds. Other work suggests that infants aged eight to 14 months *do* attend preferentially to angry compared to happy faces (LoBue & DeLoache, 2010). Taken together, these studies suggest that the normal development of an attentional bias toward indirect social cues of threat (i.e., fearful faces) may become evident around seven months, and that a bias toward signals of direct threat (i.e., angry faces) may develop a little later (i.e., by eight to 14 months). However, since these studies did not employ neutral faces, it could be that biases toward fearful and angry faces develop earlier than was evidenced in these studies, but that it takes some time before these biases emerge relative to pleasant faces.

Evidence for an attentional bias toward threat has been found in preschool-aged children. For example, Lobue and DeLoache (2008) used a visual search task and found that children detected snakes more readily than flowers, frogs or caterpillars. In another study, preschool-aged children detected angry and fearful faces faster than sad faces, and all of these faces faster than happy faces; no difference was found for angry versus fearful faces (LoBue, 2009). Thus, preschool-aged children may be biased toward negative stimuli in general, although threatening stimuli seem to capture their attention more effectively than other kinds of unpleasant stimuli.

In school-aged children, some studies have found evidence of biased attention toward threat using the dot-probe task. Waters and colleagues (2004) found that healthy children between 9 and 12 years of age exhibited a greater behavioral bias toward threat-related images (e.g. dental procedures, snakes, guns) than toward pleasant images (e.g., puppies, candy, ice cream); there was also an overall attentional bias toward both threatening and pleasant pictures compared to neutral pictures. In another study, Field (2006) found that healthy children between 8 and 10 years old showed an attentional bias toward novel animals about which they had been given negative information.² Nevertheless, in their meta-analytic study, Bar-Haim and colleagues (Bar-Haim et al., 2007) found no evidence of a threat-related bias in nonanxious children using the dot-probe task.

Research on *anxious* children, like that on anxious adults, has consistently demonstrated an attentional bias toward threat (Bar-Haim et al., 2007; Pérez et al., 2010). Vasey and colleagues (1995) found that 9- to 14-year-old children with at least one anxiety disorder exhibited an attentional bias toward threatening compared to neutral words, using the dot-probe task,³ whereas nonanxious control children did not exhibit this bias. In two recent studies using the dot-probe task in groups of children aged 8 to 12 years old and 7 to 12 years old, respectively, Waters and colleagues (Waters, Henry, Mogg, Bradley, & Pine, 2010; Waters, Mogg, Bradley, & Pine, 2008a) only found evidence for an attentional bias toward threatening stimuli among children who were severely anxious. Contrariwise, Roy and colleagues (Roy et al., 2008) found evidence of an attentional bias for threat in a group of 7- to 18-year-olds with GAD, separation anxiety disorder and social anxiety that did *not* depend on individual differences in anxiety level. These children exhibited greater threat bias scores compared to nonanxious controls using the dot-probe task and pairs of angry, happy, and neutral faces. Furthermore, attention toward threat did not vary significantly between children with GAD, separation anxiety disorder, and social anxiety, suggesting a common attentional bias across these disorders. Greater attention toward threat using the dot-probe task has also been observed in groups of children with high trait anxiety (Telzer et al., 2008). Together then, evidence from the dot-probe task is somewhat mixed regarding the existence of an attentional bias toward threat in nonanxious children; among *anxious* children, however, dot-probe task studies have provided more conclusive evidence of such a bias, though there is still some debate regarding the role of anxiety severity in moderating biased attention toward threat.

Some dot-probe studies have also provided information about the *timing* of attentional biases toward threat. Using masked presentations of emotional and neutral words in a dot-probe task, Hunt and colleagues (Hunt, Keogh, & French, 2006) found that 8- to 10-year-old children with high anxiety sensitivity showed an attentional bias toward emotional words at both short (14 ms) and long (1000 ms) stimulus presentations. Using short presentations (i.e., 17 ms) of masked stimuli in a dot-probe task with angry, happy, and neutral faces, Monk and colleagues (2008) also found evidence of an attentional bias toward threat for teenagers both with and without GAD. However, in this latter study, a correlation between attentional bias scores and amygdala activation was only observed in the anxious group, suggesting group differences in the neural correlates of threat processing. Together, these studies indicate that in children, biases toward emotional stimuli may appear very early on during stimulus processing.

One relevant question is whether an attentional bias toward threat might play a causal role in the development of anxiety or whether it might arise as a consequence of having developed an anxiety disorder (Monk et al., 2008; Pine, Helfinstein, Bar-Haim, Nelson, & Fox, 2008).⁴ Based on initial findings, some have argued that attentional biases may play a causal role in anxiety (Pérez et al., 2010). Mirroring the results from work in adults by MacLeod and colleagues (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002), Eldar and colleagues (Eldar, Ricon, & Bar-Haim, 2008) found that after being trained to attend to threatening stimuli (i.e., angry faces in a dot-probe task), healthy 7- to 12-year-old children had higher anxiety scores during a stress-induction task compared to their untrained counterparts. This provides preliminary evidence that an attentional bias toward threat may play a causal role in the development of anxiety during childhood. An interesting follow-up might be to determine whether training with other types of stimulus (e.g.,

happy faces) can similarly modulate affective states, or whether threat-related stimuli are unique in this regard.

A related question is whether an attentional bias toward threat among anxious children might dissipate following successful treatment. In contrast to those results found in adults (Mathews et al., 1995), Waters and colleagues found that attentional bias scores toward threatening pictures on the dot-probe task did not attenuate among anxious children following treatment with cognitive behavioral therapy (Waters, Wharton, Zimmer-Gembeck, & Craske, 2008b; but see Legerstee et al., 2010).

ERP STUDIES

ERPs may be particularly useful for assessing attention toward threat in children because they do not require behavioral responses. Nevertheless, ERP studies investigating attentional biases toward threat in children are relatively uncommon, and there are even fewer studies that have employed the cognitive paradigms discussed in this chapter.

Like behavioral studies, ERP studies with infants tend to use passive viewing tasks such as the VPC. These studies have often used the Negative Central (Nc)—a component with a negative-going amplitude that begins approximately 400 ms after stimulus onset and is largest at frontal and central sites—to index attention toward threat. The Nc is believed to index attention and orienting in children and infants (Courchesne, 1977; Richards, 2003).

Evidence of attention toward threat in this age group may depend on whether fearful or angry faces are used. For example, Grossmann and colleagues (2007) found no evidence of attentional biases toward threat in 7-month-olds using behavioral and ERP measures in response to angry versus happy faces. By the same token, Nelson and De Haan (1996) found larger Nc amplitudes to fearful versus happy faces in 7-month-olds. Taken together, these studies suggest the possibility that biases toward threat develop earlier for fearful than angry faces (but see Kobiella, Grossmann, Reid, & Striano, 2008 for work that has directly compared fearful and angry faces).

Even in school-aged children, there do not appear to have been any ERP studies using the dot-probe task. Nonetheless, at least one study has examined attention toward threatening stimuli using a passive viewing paradigm. Leutgeb and colleagues (Leutgeb, Schäfer, Köchel, Scharmüller, & Schienle, 2010) presented 8–12 year-old girls—some of whom were spider-phobic and some who were not—with pictures of spiders, threatening pictures, disgusting pictures, and neutral pictures. Across both groups, threatening compared to neutral pictures elicited an increased LPP; moreover, pictures of spiders elicited a larger LPP in the phobic compared to non-phobic girls. These results are in line with studies of phobias in adults (Flykt & Caldara, 2006), and suggest that even in childhood, phobias may be associated with the increased elaborative processing of phobia-relevant stimuli as indexed by the LPP.

There has also been work on the influence of environmental factors on ERP indices of attention toward threat in children. For example, Shackman and colleagues (Shackman, Shackman, & Pollak, 2007) used ERPs to study the effects of past abuse on attentional biases toward threat in a sample of children aged 7 to 12 years old. Shackman and colleagues (2007) found larger LPPs in abused versus non-abused children when children viewed their mothers' angry compared to neutral faces. There was no difference, however, in the LPP between the abused and control group when viewing pictures of strangers' angry faces. Furthermore, the relationship between experience of abuse and trait anxiety was mediated by greater attentional allocation to mothers' angry faces: abused children who attended more to their mothers' angry faces had higher trait anxiety. These results suggest that attention toward threat may provide a link between early experience and the development of childhood anxiety (Pollak, Klorman, Thatcher, & Cicchetti, 2001). Other work has also found that childhood maltreatment is associated with increased attention toward threatening stimuli, as evidenced by responses to *angry* (not *fearful*) faces (Pollak et al., 2001) and later onset ERP components (i.e., beyond 250 ms; Cicchetti & Curtis, 2005).

CONCLUSION AND FUTURE DIRECTIONS

ATTENTION TOWARD THREAT IN NONANXIOUS INDIVIDUALS

Among the tasks reviewed in this chapter, research using visual search and directed attention tasks has found evidence of an attentional bias toward threat among nonanxious individuals (Bishop et al., 2004; Flykt, 2005; Keil et al., 2005; MacNamara & Hajcak, 2009, 2010; Öhman et al., 2001a; Öhman et al., 2001b; Vuilleumier et al., 2001). Evidence of the preferential processing of threatening stimuli among nonanxious individuals has also been found using other behavioral paradigms, such as change detection (Mayer, Muris, Vogel, Nojoredjo, & Merckelbach, 2006), the attentional blink (De Martino, Kalisch, Rees, & Dolan, 2008; Maratos, Mogg, & Bradley, 2008; Milders, Sahraie, Logan, & Donnellon, 2006) and temporal order judgments (West, Anderson, & Pratt, 2009). *Behavioral* results from the dot-probe task, however, have not consistently revealed an attentional bias toward among nonanxious controls (Bar-Haim et al., 2007).

By way of contrast, ERP studies using the dot-probe task *have* found evidence of an attentional bias toward threat among nonanxious participants. Specifically, the N2pc is larger at electrode sites contralateral to the presentation of threatening stimuli, indicating greater visual attention to threatening stimuli (Holmes et al., 2008). In addition, ERPs time-locked to target onset suggest greater attentional allocation to targets that replace threatening compared to non-threatening stimuli (Pourtois et al., 2004; Santesso et al., 2008). Importantly, these ERP effects can be observed even when reaction time and error rate do not differ for threatening compared to non-threatening stimuli (e.g., Holmes et al., 2008). Thus, threatening stimuli *do* seem to bias spatial attention in the dot-probe task, although behavioral measures do not consistently capture this bias.

An important issue is whether threatening stimuli command greater attentional resources than pleasant stimuli. Like threatening stimuli, pleasant stimuli such as food and erotica are tied to biological imperatives and should capture attention. Nevertheless, it may be more important to *rapidly* identify threats than a reproductive opportunity. In line with this notion, ERP studies have generally suggested that, although pleasant stimuli also capture attention, threatening stimuli may capture attention earlier (Flykt & Caldara, 2006; Holmes et al., 2008).

Although the majority of research presented in this chapter suggests that threatening stimuli may preferentially capture attention – even compared to pleasant stimuli – it is worth noting that the kinds of stimuli vary across studies and might significantly influence results. For example, a problem with much of the work that has attempted to discern a “negativity bias” (i.e., the tendency to attend preferentially to unpleasant or threatening stimuli) has been that these studies have often failed to match threatening and pleasant stimuli in terms of their biological salience (Weinberg & Hajcak, 2010). For example, pleasant pictures have often included images of sports or babies, whereas threatening pictures tend to include images depicting human or animal threat. Indeed, when pleasant and unpleasant stimuli are matched in terms of biological imperative (e.g., erotic stimuli and mutilations), pleasant pictures elicit an LPP that is equal in magnitude to that of unpleasant stimuli (Weinberg & Hajcak, 2010) or even larger (Briggs & Martin, 2009; Schupp, Junghöfer, Weike, & Hamm, 2004).

Much of the work on attentional biases toward threat that is reviewed in this chapter has used faces, and one clear advantage is that picture complexity can be equated between conditions. However, certain types of stimulus (e.g., erotic images) may be more powerfully related to biological imperatives than smiling faces. Indeed, faces are generally less emotionally arousing stimuli relative to more complex visual stimuli (Britton et al., 2006). Future work might wish to incorporate more varied stimuli in studies of attentional bias toward threat.

ATTENTION TOWARD THREAT IN ANXIOUS INDIVIDUALS

Although evidence for an attentional bias toward threat has been well established among anxious individuals, the precise nature of this bias (e.g., the temporal dynamics) and the mechanisms

underlying biases toward threat are largely unknown. As such, future work might test more specific aspects of attentional biases toward threat in anxiety, including whether anxiety is associated with the enhanced processing of threatening stimuli in particular, or with emotional stimuli in general (Martin, Williams, & Clark, 1991). In addition, more work will be needed to reconcile evidence for both delayed disengagement and vigilance avoidance in anxiety. Specifically, future research might determine the conditions under which these different attentional patterns are observed (e.g., using speeded response versus passive viewing paradigms), or whether the temporal course of attention toward threat might vary by anxiety disorder (Fox, 2004).

Although much work has focused on the notion that anxiety is related to increased attention toward threatening stimuli in a bottom-up fashion, some recent work has indicated that anxiety is associated with decreased cognitive control, which may result in increased attention toward threatening stimuli (Ladouceur et al., 2009). For example, anxiety has been associated with the decreased recruitment of frontal brain regions linked to cognitive control when performing a distracting task (Bishop et al., 2004) and to smaller decreases in picture processing during a working memory task known to activate frontal regions (MacNamara, Ferri, & Hajcak, in press). Moreover, evidence suggests that when attentional control is high, participants high in trait anxiety may be able to overcome behavioral biases toward threatening stimuli (e.g., Derryberry & Reed, 2002). Together, these results suggest that an attentional bias toward threat in anxiety might be accompanied by less effective regulation of attention toward distracting and threatening stimuli (see also Derakshan & Eysenck, 2009; Eysenck et al., 2007).

Determining whether an attentional bias toward threatening stimuli is a state or trait marker of anxiety is also an important area for future research, and studies have begun to shed light on this question by examining whether biases toward threat vary following experimental manipulations (Eldar & Bar-Haim, 2009; Eldar et al., 2008) or successful treatment (Mathews et al., 1995; Waters et al., 2008b). Finally, the question of whether attentional biases toward threat exist among nonanxious individuals remains an important question in its own right and one which, marred by inconsistent findings, complicates interpretations of research in anxious individuals. Future research that integrates multiple measures of attention would likely be best suited to address these outstanding questions. The strengths of the ERP methodology (e.g., high temporal resolution, a highly sensitive index of attention toward threat) suggest one specific avenue.

NOTES

1. Verbal stimuli are more abstract and may be less physiologically arousing than pictures (e.g., Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009). For this reason, and because studies using pictures are more common, the majority of studies reviewed in this chapter have used images, not words.
2. This effect was only evident for stimuli presented in the left visual field, possibly because of the greater involvement of the right hemisphere in emotional processing (Field, 2006).
3. This effect was found only for stimuli in the lower visual field, which the authors suggest may have been due to a small sample size (Vasey et al., 1995).
4. Alternatively, an attentional bias toward threatening stimuli could represent a correlate of anxiety that neither causes nor results from anxiety (e.g., a third variable could be responsible for both the development of an anxiety disorder and a threat-related bias).

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