Event-related potentials of attentional bias in the facial dot-probe task

Torrence, Robert D; Troup, Lucy

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Event-related potentials of attentional bias towards faces in the dot-probe task:

A systematic review

Robert D. Torrence and Lucy J. Troup

Colorado State University

Abstract

The dot-probe task is a common task to assess attentional bias towards different stimuli and how groups differ, e.g. attentional bias in anxiety disorders. However, measuring reaction time has been suggested to be unreliable. Neuroimaging methods such as fMRI were shown to be more reliable in assessing attentional bias but fMRI has poor temporal resolution and therefore cannot assess timing of attention. Event-related potentials (ERP) have been used to examine the time-course of attentional bias. Although ERP research may be more reliable than reaction time, there have been inconsistencies in the literature. This review systematically searched for articles that used the dot-probe task with facial expressions and measured neural correlates with ERP. We found that some of the inconsistencies might be the cause of methodological differences (e.g. timing of stimuli), differences in emotional expression, and/or sample differences (e.g. sex, age, etc.). Suggestions on how future research could address the issues presented in this review were discussed.

Keywords: ERP, dot-probe, emotional faces, attentional bias

Event-related potentials of attentional bias in the dot-probe task using emotional faces: A systematic review

The ability to rapidly locate and attend towards salient stimuli has been a desirable trait during mammalian evolution. This ability allows humans (and other animals) to quickly respond to a threat before the individual is aware that the threat exists (LeDoux, 1996). The attentional bias towards threat or threat-related stimuli has been experimentally tested using a multitude of methodologies, including: attentional blink (Anderson, 2005), the Emotional Stoop task (Williams, Mathews, & Macleod, 1996), and the dot-probe task (MacLeod, Mathews, & Tata, 1986). The focus of this review was to examine the effectiveness of measuring attentional bias towards facial expressions using event-related potentials (ERP) in the dot-probe task.

The dot-probe task has been used to train attention bias towards positive stimuli and/or away from threat-related stimuli. This training is known as attentional bias modification (ABM) and has been used with the intention of reducing anxiety related symptoms (Mogg, Waters, & Bradley, 2017). Given that ABM can be used to reduce anxiety related symptoms, it is essential that researchers use a reliable method of measuring attentional bias in the dot-probe task. Although there has been a plethora of research utilizing the dot-probe task, there are many inconsistencies of results within the literature (van Rooijen, Ploeger, & Kret, 2017). Recently, researchers have used ERPs to parse out some of these inconsistencies within the behavioral literature, but even the ERP research has been inconsistent. The differences in methodologies between the ERP studies might contribute to the inconsistent results.

Dot-Probe Task

The dot-probe task is one of the most commonly used tasks to measure attentional bias. Previous researchers have used this task to explore what type of stimuli captures attention (for review see van Rooijen et al., 2017), while other researchers have used this task to explore differences between groups; in particular, differences between anxious and non-anxious individuals (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). Anxiety has been suggested to have a relationship with increased attentional bias towards threat-related stimuli. In addition to multiple uses, there are multiple versions of the dot-probe task. Typically, the task consists of two stimuli (e.g. fearful face and neutral face) presented on opposing sides of a computer monitor, whether left vs right, top vs bottom, or both (Holmes, Vuilleumier, & Eimer, 2003). After displaying stimuli, a probe appears in the location of one of the images. The duration between onset of stimuli to onset of the probe is the stimulus onset asynchrony (SOA). The participant is asked to either identify the location of the probe, or in other versions they are asked to identify the orientation of the probe, e.g. ·· or : (Mogg & Bradley, 1999; Salemink, van den Hout, & Kindt, 2007). There are typically two different trial types: congruent (probe is spatially congruent with the salient stimuli) and incongruent (probe is spatially incongruent with the salient stimuli). Reaction times (RT) of the two conditions are compared and the faster RT is thought to be due to attention allocation to the stimulus the probe followed. That is, if RT was faster for the congruent trial, then attention was oriented towards the location of the salient stimuli. Backward masking has also been used in the dot-probe task to restrict awareness of the affective stimuli. In backward masking, two stimuli appear briefly (e.g. 33 ms) and then are immediately replaced with neutral stimuli for longer (e.g. 100 ms; Carlson & Reinke, 2008).

Attentional Bias

According to Posner et al. (1980), there are three facets of attentional bias: (a) orienting towards a stimulus, (b) engaging attention to the stimulus, and (c) disengaging attention from the stimulus. Within the dot-probe task, comparing congruent with incongruent trials allows the researcher to measure overall attentional bias. This overall attentional bias does not separate the three steps of attention; therefore, more recent modifications to the dot-probe have included a baseline (e.g. neutral-neutral trial) to examine orienting effects (congruent vs baseline) and disengagement effects (incongruent vs baseline; Carlson & Reinke, 2008; Koster et al., 2004). Koster and colleagues (2004), indicated that attentional bias found in behavioral studies may not be due to rapid orientation, but due to delayed disengagement. Other research that included a baseline found rapid orientation of attention towards and delayed disengagement from fearful faces (Carlson & Mujica-Parodi, 2015; Carlson & Reinke, 2010; Carlson, Reinke, LaMontagne, & Habib, 2011) and fearful eyes (Carlson & Reinke, 2014; Carlson, Torrence, & Vander Hyde, 2016). Threat-related response slowing (i.e. behavioral freezing) might compromise differentiation of orienting and disengagement (Clarke, Macleod, & Guastella, 2013; Mogg, Holmes, Garner, & Bradley, 2008). That is, comparing an incongruent trial (e.g. fearful-neutral) and a baseline trial (e.g. neutral-neutral) might not reflect disengagement of attention, but behavioral freezing in the presence of a threatening stimulus. However, this hypothesis does not account for research that has used a fearful-fearful trial (Carlson & Reinke, 2008; Carlson, Reinke, & Habib, 2009; Carlson et al., 2011), nor the research that has indicated that RT for congruent trials was faster than baseline trials.

Although behavioral data obtained from the dot-probe task has provided understanding of attentional bias, the methods used (e.g. stimuli, SOA, etc.) and the results have been inconsistent (for reviews see Bantin, Stevens, Gerlach, & Hermann, 2016; Bar-Haim et al., 2007; Frewen, Dozois, Joanisse, & Neufeld, 2008). These inconsistencies could be attributed to unreliable equipment. If researchers use a keyboard or mouse instead of a response box, then the RT data will not be accurate (Li, Liang, Kleiner, & Lu, 2010). Another possibility for these inconsistencies could be methodological. Torrence, Wylie, and Carlson (2017) suggested that using various SOAs can cause different results in RT data. The researchers used fearful vs neutral facial expression in two different timing conditions, and happy vs neutral facial expressions in another condition. The SOAs were varied by delaying time from face offset to dot onset. They found that fearful face attentional bias, as recorded with RT, was only significant in SOAs under 300 ms of stimulus onset. That is, when fearful faces were presented for 133 ms, the shorter SOAs had significant differences in orienting and disengagement. When fearful faces were presented for 51 ms, SOAs of 84 ms and 168 ms had faster orienting towards and delayed disengagement from fearful faces. The researchers also found that happy faces had delayed orientation towards and longer engagement, relative to fearful faces. The results of Torrence and colleagues (2017) were consistent with previous research indicating that attentional orientation to emotionally salient stimuli is rapid in general samples, < 500 ms (Cooper & Langton, 2006; Koster, Verschuere, Crombez, & Van Damme, 2005). Although these studies indicate that one can measure attentional bias using the behavioral dot-probe task, other researchers have found the task to be unreliable.

The behavioral dot-probe has been suggested to be unreliable, especially when looking at individual differences, whether in nonclinical (Staugaard, 2009) or clinical (Price et al., 2015) research. Schmukle (2017) found the dot-probe task to be unreliable when using threatening and nonthreatening words and when using threatening and nonthreatening pictures. Similarly, Puls and Rothermund (2017) conducted six different dot-probe studies with different SOAs, using emotional facial expression (i.e. neutral, angry, happy, and fearful). The researchers found no reliability within or between studies. The results of these studies might suggest that the behavioral dot-probe task does not capture rapid allocation of visual spatial attention, or that there is no automatic capture of attention by emotional stimuli. As mentioned earlier, non-attention related processes like behavioral freezing might affect RT data. Measuring attentional bias with alternative methods might be more reliable.

Eye-tracking is one method used to measure attentional bias towards emotional stimuli during the dot-probe task. Petrova, Wentura, and Bermeitinger, (2013) used eye-tracking to examine the effects of eye movements in the dot-probe task (angry and neutral faces presented horizontally). The researchers found that when participants were urged to restrain eye movements, RT biases were significant (i.e. faster RT to angry congruent than angry incongruent), whereas when they were not instructed to maintain eye gaze, RT was not significant. Recent research has examined the reliability of using eye-tracking to measure attentional bias. Price et al., (2015) and Waechter, Nelson, Wright, Hyatt, and Oakman, (2014) used a facial dot-probe task and presented the faces stacked vertically (top and bottom of the computer screen). The two studies found that using standard RT scores to measure attentional bias was not reliable and that using eye-tracking was more reliable; however, reliability was still low in Waechter et al. (2014). The results from both studies indicated that participants looked up initially, regardless of facial expression. Eye-tracking seems to be more reliable than using RT when measuring overt attention, but it cannot measure covert attention.

Neural Correlates of Attentional Bias

Human lesion studies have suggested that the amygdala is necessary for allocating attentional resources towards a threatening stimulus in the attentional blink task (Anderson & Phelps, 2001) and the visual search task (Bach, Hurlemann, & Dolan, 2015). Given the presumed role of the amygdala in emotional processing, it is not surprising that previous fMRI research has shown that the amygdala is correlated with attention towards emotionally salient stimuli, whether negative or positive (Garavan, Pendergrass, Ross, Stein, & Risinger, 2001; Hamann & Mao, 2002; Yang, Dong, Chen, & Zheng, 2012). In response to fearful facial expression, Vuilleumier, Richardson, Armony, Driver, and Dolan (2004) found that patients with amygdala damage also had decreased activity in the visual cortex. In addition to the amygdala, the modulation of attention by emotional stimuli appears to involve the anterior cingulate cortex (ACC), medial prefrontal cortex (mPFC) and anterior insula (Carlson, Cha, & Mujica-parodi, 2013; Carlson, Reinke, & Habib, 2009; Fu, Taber-Thomas, & Pérez-Edgar, 2015; Liddell et al., 2005; Price et al., 2014; White et al., 2016a). The ACC and other prefrontal regions appear to be particularly important for regulating the duration of attentional engagement and subsequent disengagement (Fu et al., 2015; Price et al., 2014). One of the consequences of the amygdala-facilitated enhancement of attention is increased processing in sensory cortices. For example, visual cortex activity is correlated with amygdala activity when attending to fearful faces (Morris et al., 1996; Pessoa, Kastner, & Ungerleider, 2002). In the dot-probe task, emotional faces have also been found to enhance activity in the visual cortex (Carlson et al., 2011; Pourtois et al., 2006), which correlates with increased amygdala activity (Carlson et al., 2009). Thus, the amygdala appears to be at the heart of an emotion-based attention system that involves areas of the prefrontal cortex and sensory cortices.

The reliability of assessing attentional bias using fMRI has been empirically tested and has been found to be more reliable than behavioral measures alone (White et al., 2016). Thus, neuroimaging research has alleviated some of the issues in measuring attentional bias by not relying on overt behaviors (i.e. RT and eye movements). Although research utilizing fMRI has explained the locations of the brain involved in attentional bias, the time-course of attention bias in the brain remains poorly understood. One method to better understand the time course of attentional bias is the event-related potential (ERP) approach. ERPs are based on electroencephalography (EEG) recordings that are time-locked and averaged across events of interest (e.g. emotional stimulus onset). Typically, ERP waveforms have similar components, but the components may vary in amplitude and latency, and may also depend on location of electrode. In the dot-probe task, the ERP wave can be time-locked to emotional stimulus onset or target onset. That is, the researcher can examine the ERP components related to the onset of the stimuli (e.g. faces) or the onset of the target. Based on the neural correlates of attention bias reviewed above, ERPs with a more anterior—or frontal—scalp distribution would be more likely to represent the time-course for engagement/disengagement processes, while ERPs with a more posterior—or sensory—scalp distribution would be more likely to represent the consequences of attention on sensory processing.

Posterior ERP components. Martínez et al., (1999) found that early response of V1, as measured by the C1 ERP component, was related to allocation of attention, and increased activity in V1 using fMRI. The researchers suggested that higher extrastriate areas may send feedback to V1. Additionally, the earliest attentional responses in the striate cortex occurred near the onset of the P1 response, approximately 70 - 75 ms after stimulus presentation. The P1 component has a positive peak around 100-130 ms post stimulus onset and is typically strongest in the lateral occipital electrodes. Previous research has found that P1 amplitude was greater when attending to a stimulus in an already attended location (Mangun, Hopfinger, Kussmaul, Fletcher, & Heinze, 1997). That is, P1 was greater when there was less perceptual load. The N1 component is the first negative deflection after the P1 component and can be seen in the anterior (peak around 100-150 ms) and the posterior (peak around 150-200 ms) electrodes (Luck, 2014).

Only the posterior N1 will be referenced in this review since the it is the only one used in the dot-probe literature. The N170 is sensitive to faces, exhibiting a negative peak around 170 ms, and is found in lateral posterior electrodes (Bentin, Allison, Puce, Perez, & Mccarthy, 1996). A recent meta-analysis concluded that the N170 is enhanced by facial expressions and is especially sensitive to angry, fearful, and happy facial expressions (Carretie, Hinojosa, Martı, Mercado, & Tapia, 2004). Another ERP component that is used in attentional bias research is N2pc. The N2pc is a negative component occurring around 150 – 250 ms after stimulus onset, and is found in posterior electrodes contralateral to the salient stimulus. Enhancement (i.e. more negative amplitudes) of the N2pc is thought to indicate initial orientation of attention (Diao, Qi, Xu, Fan, & Yang, 2017; Dowdall, Luczak, & Tata, 2012; Luck & Hillyard, 1994a, 1994b; Tan & Wyble, 2015)

Anterior ERP components. The P2 component, appearing after N1, typically peaks around 200 ms in anterior and central electrodes (Luck, 2014). In visual attention research, the P2 has been localized to the ACC (Carretie et al., 2004) and has been suggested to indicate the allocation of attentional resources during the processing of emotional facial expressions (Bar-Haim, Lamy, & Glickman, 2005; Eldar, Yankelevitch, Lamy, & Bar-Haim, 2010). The anterior N2 component, which is involved in cognitive control (e.g. controlling actions), has a negative deflection after P2 peaking around 250-300 ms in the frontocentral electrodes (Folstein & Van Petten, 2008). The P3 is a positive component around 250-500 ms in the frontal to parietal electrodes and has been associated with attentional processing (Polich, 2007). Specifically, emotional content of attended stimuli further increases the amplitude of the P3 (Johnston, Miller, & Burleson, 1986).

Purpose

Recent reviews (Bantin et al., 2016; Bar-Haim et al., 2007; Frewen et al., 2008; van Rooijen et al., 2017) and empirical evidence (Price et al., 2015; Staugaard, 2009) suggested that relying on RT to study attentional bias is difficult and different methodologies used could affect our understanding of the time-course of attentional bias towards facial expressions. In addition, fMRI has been more reliable than RT in measuring attentional bias (White et al., 2016) but has very poor temporal resolution. As discussed above, ERP components may be more reliable than RT but some inconsistencies still exist in the literature. The focus of this review paper was to examine the literature that used ERPs to measure attentional bias towards, or avoidance of, emotional facial expressions using the dot-probe task.

There is not one standard method of dot-probe; therefore, this review grouped like articles (e.g. facial stimuli, sample type) together and then compared the groups of articles to each other. Given that faces and non-facial images affect early ERP components differently, this review only focused on attentional bias to facial expressions (Wang, Jin, Liu, & Yin, 2017). Additionally, only articles that used horizontal presentation of facial stimuli were included since eye-tracking research has demonstrated that there is an inherent bias upward (Price et al., 2015; Waechter et al., 2014) and we wanted to keep the methodologies relatively similar to reduce confounds. Therefore, the purpose was to get a clear understanding of the time-course of attentional bias towards facial expressions by discussing the ERP results of the various dot-probe methodologies used in research and offer suggestions on how to address some inconsistencies. Since previous reviews and studies have discussed concerns with behavioral data (Bantin et al., 2016; Bar-Haim et al., 2007; Price et al., 2015; Staugaard, 2009; van Rooijen et al., 2017), RT results are not discussed.

Method

To identify articles that examined ERP components in the dot-probe task, a two-stage systematic approach was used on 1 March 2017. The initial search was conducted in PsychInfo (with all sub-databases) and Pubmed with the search terms ((“dot probe” OR “dot-probe” OR “probe detection”) AND (“ERP” OR “event related potential”)). The following seven predetermined criteria were necessary for further inclusion:

1. Scholarly (peer reviewed) journal article
2. Empirical study (no reviews or meta-analyses)
3. Adult (+18) human participants
4. Used the dot-probe task concurrently with EEG (with the purpose of examining ERPs) in the methods
5. The stimuli in the dot-probe task must have been presented horizontally
6. Emotional facial expressions must have been used in the dot-probe task
7. Only two stimuli could be presented at the same time with one target stimuli

After the initial search, the resulting articles’ references were examined to ensure all relevant articles were included. Related systematic reviews and meta-analyses’ references were also examined. There were no exclusion criteria for type of participant samples (e.g. depression, PTSD, anxiety, etc.). Effect sizes was not analyzed because of differences in ERP component selection, differences in the type of emotional facial expressions utilized, and differences in the timing methods used within the task.

The jargon for attentional bias research is varied; therefore, we used one set of jargon for ease of discussing the results of the studies. For the purposes of this review, trials in which a target stimulus (i.e. probe) appeared spatially congruent with the affective stimuli (e.g. fearful face) were defined as congruent trials, whereas trials in which the target appeared spatially incongruent to affective stimuli (same location as neutral stimulus) were known as incongruent trials. Since the purpose of this review was to examine the ERP of attentional bias, the behavioral data will not be discussed in the results.

Results

Twenty-three articles published between 2004 and 2017 fit the search criteria. A summary of each article is presented in Table 1. Within these 23 articles, 15 had a general sample (e.g. did not select or examine subclinical and/or clinical differences) and eight had subclinical and/or clinical samples; four studies of which looked at anxiety, three studies examined social anxiety, and one study looked at the effects of escitalopram on attentional bias in panic disorder. One of the anxiety articles and three of the general participant articles used ABM.

There were many differences in methodology and stimuli used among the 23 articles included in this review. In total, the facial expressions used were fearful, angry, happy, disgust, and neutral. All but one article (O'Toole & Dennis, 2012; only used angry and happy) paired emotional faces with neutral faces. Six articles used fearful faces, 17 articles used angry faces, 11 articles used happy faces, three articles used disgust faces, and one article did not specify but used aversive facial expressions. Five articles displayed the faces and targets horizontally but in the upper visual field (Mueller et al., 2009; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Pourtois, Thut, De Peralta, Michel, & Vuilleumier, 2005; Santesso et al., 2008; Zhou, Cao, Li, & Li, 2014), whereas the other 18 articles had the stimuli in the central visual field.

INSERT TABLE 1 ABOUT HERE

Attentional bias in the general population

Attentional bias towards angry faces. Out of 15 articles that used a general sample, there were seven that included angry facial expressions (Brosch, Sander, Pourtois, & Scherer, 2008; Holmes et al., 2009, 2014; Liu, Zhang, & Luo, 2013; Pfabigan, Lamplmayr-Kragl, Pintzinger, Sailer, & Tran, 2014; Santesso et al., 2008; Zhang, Liu, Wang, Ai, & Luo, 2016). Each article displayed an angry facial expression and a neutral facial expression. Only two articles had a baseline (i.e. neutral-neutral trial; Liu et al., 2013; Zhang et al., 2016). For ERP components time-locked to face onset, Santesso et al. (2008) found no differences in C1, P1, and N170. However, Holmes et al. (2009, 2014) found enhanced early N2pc (180-250 ms), late N2pc (250-320 ms), and sustained posterior contralateral negativity (SPCN; 320-500 ms) to angry facial expressions. Holmes et al. (2014) examined the effects of working memory (WM) load on attentional bias and found that the enhanced early N2pc, late N2pc, and SPCN to angry faces were only significant during high WM load.

For ERP components time-locked to target onset, Brosch et al. (2008), Liu et al. (2013), and Santesso et al. (2008) found more positive P1 amplitudes in angry congruent trials compared to angry incongruent trials, whereas Pfabigan et al. (2014) found no differences in congruency in P1 amplitudes for angry trials. Santesso et al. (2008) indicated no differences in C1 and N1 amplitudes for either trial type in angry trials. Zhang et al. (2016) found that in backward masked trials, the N1 was enhanced for angry congruent compared to angry incongruent trials. In addition, Zhang et al. (2016) also reported that the P3 component was significantly increased for congruent trials, regardless of the emotion condition. That is, the P3 amplitude was greater for fear, disgust, and angry congruent trials compared to the respective incongruent trials. Liu et al. (2013), however, stated that angry congruent trials had a smaller P3 than angry incongruent, but only in non-foreign faces. Zhang et al. (2016) did revisit the unmasked P3 (450-650 ms) data from Liu et al. (2013) and examined the P3a (280-400 ms) and P3b (500-680 ms) components. They found that the P3a amplitude was greater for congruent compared to incongruent trials for angry. They also found that the P3b amplitude was greater for incongruent trials compared to congruent trials.

Attentional bias towards disgust faces. Only two articles (Liu et al., 2013; Zhang et al., 2016) used disgust facial expressions. Liu et al. (2013) indicated that the P1 component time-locked to target onset was smaller for disgust congruent compared to incongruent trials. They found the opposite effect in P3 amplitudes. Using a backward masked paradigm, Zhang et al. (2016) found that the amplitude of the N1 component, time-locked to target onset, was enhanced for congruent trials when compared to incongruent trials. Results also indicated that congruent trials exhibited a greater P3 amplitude than the incongruent condition, regardless of emotion (i.e. disgust, fear, and anger). In Zhang and collegues' (2016) reanalysis of (Pourtois, Grandjean, Sander, et al., 2004) P3 data, the amplitude for the P3a and P3b components was greater in disgust congruent trials compared to incongruent trials.

Attentional bias towards fearful faces. Five articles included fearful facial expression (Brosch et al., 2011; Carlson & Reinke, 2010; Pourtois, Grandjean, & Sander, 2004; Pourtois et al., 2005; Zhang et al., 2016). ERP components time-locked to face onset revealed that the C1 amplitude was greater when fearful faces were present, than when happy faces were present, and no differences were found in P1 (Pourtois et al., 2004). Two articles examined the N170 component time-locked to face onset. Carlson and Reinke (2010) found that when fearful faces were masked, there was an enhancement in N170 amplitude contralateral to the fearful face. However, Pourtois et al. (2004) indicated that there was no difference in N170 amplitudes between conditions. There were no differences in N2pc for fearful faces (Brosch et al., 2011).

As for ERP components time-locked to target onset, there were no differences in C1 amplitude (Pourtois et al., 2004). The P1 component was enhanced for fear congruent trials when compared to fear incongruent trials (Brosch et al., 2011; Pourtois et al., 2004, 2005). In addition, Pourtois et al. (2005) used source localization and found that P1 activity was localized to the posterior pariatal and inferior temporal cortecies for congruent trials, whereas P1 activity was localized to medial frontal/anterior cingulate areas for incongruent trials. Pourtois et al. (2004) found no differences in N1 amplitude between the two conditions. Zhang et al. (2016) used backward masked trials and found an enhancement of N1 in congruent trials when compared to incongruent trials. In their study, the P3 component was enhanced for fear congruent trials in comparison to incongruent trials.

Attentional bias towards happy faces. There were five articles that examined attentional bias towards happy facial expressions (Holmes et al., 2009; Pfabigan et al., 2014; Pourtois, Grandjean, Sander, et al., 2004; Pourtois et al., 2005; Santesso et al., 2008). For ERP components time-locked to face onset, there was no significant difference in C1, P1, and N170 (Pourtois et al., 2004; Santesso et al., 2008). There was a significant difference in late N2pc and SPCN, but not in early N2pc for the happy-neutral trials (Holmes et al., 2009). There was significant finding for ERP components time-locked to target onset. Santesso et al. (2008) indicated that the P1 amplitude was significantly enhanced for right visual field happy incongruent trials when compared to happy congrunet trials. Pfabigan et al. (2014) examined sex differences in attentional bias and found that women had enhanced P1 amplitudes for happy congruent trials compared to men. However, Pourtois et al., (2004, 2005) found no differences in C1, P1, and N1 for happy trials.

Attentional bias towards adversive faces. One study did not specify the emotional facial expression that was used except for the fact that it was adversive. Yang et al. (2012) used negative and neutral images as primes before the onset of the dot-probe task. They found that the N1 time-locked to face onset was enhanced for faces that followed a negative prime when compared to a neutal prime. Conversely, the P1 amplitude was enhanced for faces succeeding neutral primes when compared to negative primes.

Attentional bias in anxiety related disorders

Trait anxiety. There were two articles that examined trait anxiety related attentional bias (Eldar et al., 2010; Fox et al., 2008). Both articles used angry and happy facial expressions. Eldar et al. (2010) suggested the C1 component time-locked to face onset was significantly enhanced (more negative) for the anxious group during angry-neutral trials, and there were no group differences in happy-neutral trials and neutral-neutral trials. The researchers also found that the P2 amplitude was greater for the anxious group in all trial types when compared to the non-anxious group. They found no group differences in P1 and N1 time-locked to face onset. In Fox et al. (2008), the anxious group had a significant enhancement of the N2pc time-locked to face onset towards angry faces, whereas the non-anxious group was not significant. Neither group had differences in N2pc for happy faces. Fox et al. (2008) also indicated that the P1 time-locked to target onset was significantly enhanced for angry congruent trials compared to incongruent trials when there was a short delay between face and target (150 ms vs. 600 ms). The differences for happy faces were only trending but there was a greater P1 amplitude for happy incongruent than congruent in the short delay trials. No differences were found in the long delay trials and no group differences were found in P1 time-locked to target onset. Eldar et al. (2010) found no differences for P1 time-locked to target onset in angry and happy trials.

Social anxiety. There were four articles that looked at social anxiety (Helfinstein, White, Bar-Haim, & Fox, 2008; Mueller et al., 2009; Reutter et al., 2017; Rossignol, Campanella, Bissot, & Philippot, 2013). Helfinstein et al. (2008) used neutral and social threat words as primers to the dot-probe task where they used angry and neutral facial expression. The researchers found that in ERP components time-locked to face onset, the high social anxiety group (HSA) had significantly higher P1 amplitudes than the low social anxiety group (LSA). The LSA had lower N1 amplitudes than the HSA. The P2 differences were approaching significance for the HSA which exhibited greater amplitudes than the LSA. There were no interactions of group and prime type.

Mueller et al. (2009) suggested that within the HSA, the P1 amplitude time-locked to face onset was larger for angry-neutral when compared to happy-neutral trials. There were no group differences in P1 amplitude. Interestingly, Rossignol et al. (2013) indicated that P1 amplitude was greater in the left hemisphere for fear and disgust but not happy in the LSA. These differences were not seen in the HSA. The researchers stated that there were no group differences for the N170; however, the N170 was enhanced in the left hemisphere for contralateral emotional faces. Reutter et al. (2017) found an overall difference in N2pc towards angry faces. They did find a correlation between N2pc amplitudes and scores on the Social Interaction Anxiety Scale (SIAS), in that higher scores on the SIAS were correlated with lower (enhanced) N2pc amplitudes. Rossignol et al. (2013) indicated that there was no difference in P2 amplitudes for LSA, but HSA had higher amplitudes for angry-neutral when compared to fear-neutral trials. There was an overall increase in P1 time-locked to target amplitude for fear, angry, and happy congruent trials and an increase in amplitude for disgust incongruent trials. There was also an increase in P1 amplitude for congruent trials in HSA regardless of emotion, but no differences in LSA. While Mueller et al. (2009) found that P1 target amplitude was smaller for congruent trials when compared to incongruent and LSA had a smaller P1 for incongruent trials when compared to congruent trials, both results were independent of emotional expression (angry and happy).

Panic disorder. Zhou et al. (2014) was the only article that examined panic disorder. They also examined the effect of escitalopram (a serotonin reuptake inhibitor) after eight weeks of treatment. At baseline, the panic disorder group (PD) had significantly more negative C1 time-locked to face onset amplitude to angry-neutral trials when compared to controls, but no differences in happy-neutral trials. After the eight weeks of treatment, there were no differences in C1 amplitude for either group in trial types.

Attentional bias modification

There were four articles that used ABM, three of which used a general sample (O'Toole & Dennis, 2012; Osinsky, Wilisz, Kim, Karl, & Hewig, 2014; Suway et al., 2013), and one examined anxiety (Eldar & Bar-Haim, 2010). Osinsky et al. (2014) examined the effects of short ABM training on the N2pc time-locked to face onset. Their paradigm consisted of one testing block, four ABM blocks, and one final testing block (80 trials per block). They did two different experiments: one in which participants indicated the location of the target (i.e. left or right), and the other where participants discriminated the orientation of the target (i.e. up or down arrow). In both experiments, the researchers found there was enhanced N2pc towards angry faces, but no training effect. The enhanced N2pc was consistent across blocks. Similarly, Suway et al. (2013) used short ABM to train towards threat: two blocks of 300 trials between the pretraining and posttraining blocks. The training group only had angry congruent trials in the ABM blocks, whereas the control group had an equal number of congruent and incongruent trials. They found no group differences in P1 and N1 time-locked to face onset amplitudes. There was a significant group difference in that the training towards threat group had greater P2 amplitudes time-locked to face onset than controls in the posttraining block. There were no differences in P3 time-locked to target onset amplitudes.

Unlike Suway et al. (2013) who used angry-neutral face pairings, O'Toole & Dennis (2012) used angry-happy and happy-happy face pairings to train attention towards angry in one group and towards happy in another. For ERPs time-locked to face onset, participants that were trained away from threat had a decrease in P1 amplitude to all face pairings from pretraining to posttraining when faces were presented for 100 ms (compared to faces being presented for 500 ms). The N170 and N2 were significantly diminished from pretraining to posttraining. Duration also affected N170 and N2 as these components were more negative for faces presented for 500 ms when compared to 100 ms. Amplitudes for P2 and P3 increased from pretraining to posttraining. P3 amplitude was greater when faces were presented for 100 ms compared to 500 ms, and P3 was greater for happy-happy in comparison to angry-happy trials. Similar results were found for P3 time-locked to target onset.

Eldar & Bar-Haim (2010) used a short ABM using angry and neutral facial expressions to train away from threat, but with the inclusion of anxiety groups based on scores from the trait scale of the State–Trait Anxiety Inventory (STAI). For ERP components time-locked to face onset, the researchers found no significant difference in P1 amplitudes, but they found a decrease (less negativity) in N1 amplitudes from pretraining to posttraining. In addition, the anxious trained group had reduced P2 amplitudes and the anxious control group had increased P2 amplitudes from pretraining to posttraining. Similarly, from pretraining to posttraining, the anxious trained group had more negative N2 and the anxious control groups had more positive

N2 amplitudes. There was a reduction of P3 amplitude from pretraining to posttraining in both non-anxious groups and in the anxious trained group. No differences were found in the anxious control group. There was an increase in P3 time-locked to target onset amplitudes from pretraining to posttraining for angry incongruent trials in both training groups.

Discussion

The aim of the present study was to systematically review the literature on using ERPs to measure attentional bias to emotional facial expressions. Even with some inconsistencies in the results, there were strong indications of an attentional bias towards threatening stimuli in unselected samples and in high anxiety related samples. Specifically, attentional bias towards fearful and angry facial expressions can be seen in early ERPs time-locked to face-onset, N170 (Carlson & Reinke 2010) and N2pc (Holmes et al., 2009, 2014). The P1 component has been suggested to be enhanced when a stimulus is presented in an attended location compared to an unattended location (Mangun et al., 1997). Some of the P1 time-locked to target onset results indicated that for angry and fearful congruent trials, attention was allocated to that location (Brosch et al. 2008, 2011; Liu et al. 2013; Pourtois et al., 2004, 2005; & Santesso et al. 2008). That is, attention was oriented towards the location of the threatening facial expression and was sustained in that location when the target appeared.

As stated previously, using RT to measure attentional bias has not been reliable (Bantin et al., 2016; Bar-Haim, 2010; Frewen et al., 2008; van Rooijen et al., 2017) and the use of ERP may be a desirable alternative. Researchers have been using ERPs as a more reliable measure (Kappenman, MacNamara, & Proudfit, 2015); however, as the results of this review have indicated, using ERPs has not been consistent when measuring attentional bias towards emotional facial expression. The discrepancies in the literature could be the cause of different facial expressions, methodologies used, and different samples (e.g. sex, anxiety, etc.).

Facial expression differences

Research using behavioral data has indicated that fearful faces capture visuospatial attention early, whereas happy faces capture attention later (Torrence et al., 2017). Using early and late N2pc, similar results were found in regards to angry and happy facial expressions (Holmes et al., 2009). That is, angry faces captured attention early, whereas happy faces had a delayed capture of attention. Other studies examined disengagement and reorienting by using the P1 time-locked target onset which found that angry (Brosch et al., 2008; Fox et al., 2008; Liu et al., 2013; Mueller et al., 2009; Santesso et al., 2008) and fearful (Brosch et al., 2011; Pourtois, Grandjean, Sander, et al., 2004; Pourtois et al., 2005) congruent trials had greater amplitudes than incongruent trials. This would indicate that there was interference during incongruent trials for angry and fearful. Researchers have used source localization to identify the source of the P1 component and found that P1 was located in the ACC for both angry (Santesso et al., 2008) and fearful (Pourtois et al., 2005) incongruent trials. Previous fMRI studies have also indicated that the ACC is involved modulation of attention (Armony & Dolan, 2002; Carlson et al., 2013; Liddell et al., 2005). Taken together, when attention is allocated to the location of the threat related facial expression, the ACC is involved in disengaging and relocating attention to the target during incongruent trials. Happy faces, however, have an opposite effect on the P1 target amplitude, as P1 amplitude was greater for incongruent trials than for congruent trials (trending in Fox et al., 2008; Santesso et al., 2008), indicating that happy has different attentional processes. Other researchers found no differences in P1 target to happy trials (Eldar et al., 2010; Pourtois et al., 2004, 2005). Some of the literature has indicated differences between positive and negative facial expressions, but what is less clear are the differences between angry and fearful facial expressions.

Fearful faces indicate a threat in the environment while angry faces are the threat. Only one study included angry and fearful facial expression (Zhang et al., 2016) and found no differences between angry and fearful N1 time-locked to target onset. Both fearful and angry facial stimuli had enhanced N1 for congruent trials compared to incongruent. Other research has found no differences in N1 for fearful faces (Pourtois et al., 2004) and angry faces (Eldar et al., 2010). In a recent study, Diano et al. (2017) examined the neural networks of emotional facial expression. They found that all expressions (angry, fearful, happiness, sadness, and disgust) had greater amygdala activity than neutral faces. However, each emotion had a different neural network. In particular, angry faces enhanced the connectivity between the amygdala and the right posterior cingulate cortex (PCC) and the bilateral precuneus, while fearful faces enhanced connectivity with visual areas (striate cortex, middle occipital gyrus, middle temporal gyrus, superior temporal sulcus, and superior temporal sulcus). Given the different neural networks angry and fearful faces have (and other facial expressions; see Diano et al., 2017), ERPs may make it difficult to fully understand the differences in the time-course of attentional bias.

Methodological differences

In the 23 articles that were included in this review, there was an array of methodological differences. That is, there were differences in the dot-probe task: stimulus display time, delay SOA, target presentation time, target type, type of response, percent of motor response, and position of stimuli (i.e. horizontal or upper horizontal). There were also differences in timing of the ERP component. Some researchers chose the timing based off their data, some used previous data, and others did not indicate how they determined the timing.

Differences in timing. Stimulus display time varied from 100 ms to 500 ms not including experiments that used backward masking (emotional trial 33 ms/mask 100 ms, Carlson & Reinke, 2010; 17/83 ms, Zhang et al., 2016). O'Toole and Dennis (2012) were the only researchers to include different stimulus display times (100 ms and 500 ms). The ABM training decreased P1, time-locked to face onset, amplitude only in the 100 ms condition. Regardless of training, N170 and N2, both time-locked to face onset, had enhanced (more negative) amplitudes in the 500 ms condition compared to the 100 ms condition. Whereas there was greater P3 time-locked to face and target amplitudes in the 100 ms condition compared to the 500 ms condition. Therefore, differences found between studies could be caused by differences in stimulus display time. In one case, P1 amplitude was greater for happy incongruent trials when the stimuli were presented for 100ms (Santesso et al., 2008), but there were no differences in P1 amplitude when stimuli were presented for 500 ms (Eldar et al., 2010). Comparing results between studies proved to be difficult given that all the studies that used 100 ms stimulus presentation varied the SOA from 100 ms to 300 ms; whereas most of the studies that used 500 ms stimulus presentation had no SOA.

As Pourtois et al. (2004) stated, the reason for varying the SOA (100, 150, 200, 250 or 300 ms) was to create a stable baseline in the ERP data and by including short SOAs, they were able to ensure testing of stimulus-driven attention instead of goal-driven attention (see Table 1 for the other studies that had similar SOAs). Fox et al. (2008) did study the differences between short (150 ms) and long (600 ms) SOAs when faces were displayed for 150 ms. The researchers found that the P1 target amplitude was significantly greater for angry congruent trials than incongruent trials in the short SOA condition, and no differences for the long SOA condition. These results suggested that by 600 ms, attention had already disengaged from the angry face before the target was presented. Therefore, when examining ERP components time-locked to target onset, the duration of the SOA is important.

Response type to target. There are two ways the participants responded to the target: identifying the location of the target or identifying the orientation of the target (e.g. vertical or horizontal bar). These two methods require different levels of processing. In the location condition, attention is not required to engage in the target to identify its location, whereas in the orientation condition, attention does need to engage in the target to determine its orientation. Eighteen studies used the orientation method, four studies used the location method, and one study used both (see Table 1). Osinsky et al. (2014) directly compared the two different methods and how they might affect ERP data and the effectiveness of ABM. They found that there was no difference in N2pc and no difference in ABM effectiveness between the two methods. However, the researchers did not examine ERPs that were time-locked to target onset. Comparing results of the reviewed literature would indicate that response type to target would not affect the ERPs time-locked to target onset. Using similar methodologies in SOA and including angry facial expressions, there was greater P1 target amplitude for angry congruent trials compared to incongruent trials when participants identified the location of the target (Liu et al., 2013) and when identifying the orientation of a bar (Santesso et al., 2008). Even though these two studies found similar results, no research has directly compared the different target response effects on ERP components time-locked to target onset. On a behavioral level, participants had slower RTs and more errors when identifying the orientation of a target compared to identifying its location (Mogg & Bradley, 1999). Thus, using the orientation of the target method may increase cognitive load and therefore the ERP results might not reflect attentional processes, even with no required motor response (Fu, Fedota, Greenwood, & Parasuraman, 2010).

Motor movement. To ensure the ERP components were measuring attentional processes and not motor planning and movement, some researchers have only analyzed nonmotor response trials (no-go trials). Of the 23 articles, nine used no-go trials in their analysis (see Table 1). In these experiments, the target always appeared but the participant was asked to only respond to a specific type of target (i.e. horizontal or vertical bar and up or down facing triangle). Given that participants were required to determine the orientation even when not responding, the ERPs could be unintentionally measuring cognitive load. It is difficult to analyze the literature for the effect motor responses have in the dot-probe task since 12 of the 14 articles that did not include no-go trials had a stimulus presentation time of 500 ms, and none of the no-go trial experiments had that long of a presentation time. Carlson and Reinke (2010) required responses for all trials in a backward masking paradigm. In their experiment, the fear-neutral faces were presented for 33 ms and masks for 100 ms with the target following the masks immediately. Even when using motor responses, contralateral N170 amplitude to fearful faces was more enhanced; however, the researchers did not examine ERPs time-locked to target onset. O'Toole and Dennis (2012) did not include any no-go trials, did have a stimulus presentation time of 100 ms, and did analyze the P3 time-locked to target onset, but, they had an SOA of 500 ms. Given the SOA discrepancies, comparing the results to the research that used no-go trials would not be appropriate. Future research could directly test whether motor responses in the facial dot-probe task affect ERPs.

Sample differences

Sex differences. Of the 23 articles, two used only female participants. Some of the articles were close to a 1:1 ratio, whereas in others, the ratio was more drastic (with consistently greater participation of females). This could be problematic in analyzing the ERP data. Previous behavioral research has indicated that there are differences between males and females in attentional bias. Females may have an attentional bias towards angry facial expressions, whereas males do not (Tran, Lamplmayr, Pintzinger, & Pfabigan, 2013). Males and females also had differences in attention related ERPs. Using the Stroop task, males had greater amplitudes in early ERP components for threat, whereas females had greater amplitudes in later ERP components for threat (Sass et al., 2011). A dot-probe ERP study using positive, negative, and neutral images found that only females had greater P1 target amplitudes for negative congruent compared to positive congruent, and greater P2 amplitudes for negative congruent compared to negative incongruent (Pintzinger et al., 2016). Only one study included in this review examined sex differences. Pfabigan et al. (2014) found that females had greater P1 amplitudes for happy congruent than for incongruent trials, and males did not show this effect. However, there were no differences between sex for angry trials. In all, there seems to be sex differences in attentional biases towards emotional stimuli. Future research should account for sex differences by having equal sample sizes and testing for any effects potentially driving the results.

Anxiety related differences. As discussed in the results section, participants with anxiety related disorders/symptoms have different attentional biases than low-anxiety participants. Consistent with previous literature (for review see Bar-Haim et al., 2007), individuals with high anxiety have an attentional bias towards negative stimuli, more so than low anxiety participants, as measured by the N2pc (Fox et al., 2008; Reutter et al., 2017), P1 face onset (Helfinstein et al., 2008; Mueller et al., 2009), N170, and P2 (Rossignol et al., 2013). A meta-analysis indicated that depression may also be related to attentional bias towards negative stimuli in the emotional Stroop and dot-probe task (Peckham, McHugh, & Otto, 2010). However, no research to date has examined attentional bias towards emotional face differences in depression using the dot-probe task and ERPs.

Conclusion

The dot-probe task has been a widely used task to examine visuospatial attentional bias towards a variety of stimuli. Relying on behavioral RT may not be the most reliable method to measure the attentional biases. Although neuroimaging methods such as fMRI are more reliable than RT (White et al., 2016), they do not have the temporal resolution to measure the rapid attentional processes. However, by utilizing ERPs, research can measure rapid orientation and disengagement of attention. This review sought out to examine the methods used in the literature that used ERPs to measure attentional bias to facial expression. The findings suggested that although ERPs may be more reliable and consistent than solely relying on RT, there were inconsistencies in the literature. The inconsistencies in these results could be mended by future research experimentally testing the various methods used. The dot-probe task has added a significant amount of understanding to attentional bias by providing evidence that there is a neurological basis for attentional bias towards, or avoidance of, emotional faces as seen in the N2pc to faces and the P1 to targets. However, given that the dot-probe task was designed to measure RT, a new task that can reliably assess differences in orientation, engagement, and disengagement using ERPs, or other EEG methods like time-frequency analysis.

Although this review offered a detailed comparison between the studies included in the literature, there were some limitations. Only studies that used facial expression were included which does not lend to a comprehensive understanding of attentional bias towards emotional stimuli. Effect sizes were not analyzed because of the small amount of similarity between studies. This includes differences in stimuli, task design, and ERP components analyzed. Even with these limitations, this review highlights the necessity for future methods research.

Systematizing the methods would offer a more complete understanding of the time-course of attentional biases and the individual/group differences in attentional bias.

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Table 1

Summary of included articles

Author	Year	Stimuli	Participants	Sex	Target task	% Resp	Stim (ms)	Delay (ms)	Probe (ms)	ERP Components (window in ms)	Findings
Brosch et al.	2008	Angry and neutral adult faces AND neutral infant and adult faces	General *N* = 19	F = 15 M = 5	Ori	10%	100	100-300	150	P1 target (120-170)	Congruent trials with adult angry and baby faces had greater P1 amplitudes driven by LVF cue, no latency. P1 located in striate and extrastriate visual cortex.
Brosch et al.	2011	Fearful and neutral faces	General *N* = 18	F = 11 M = 7	Ori	10%	100	100-300	150	N2pc face (180-300) P1 target (80-180)	Greater N2pc for exogenous cue but no differences for emotion. Greater P1 in congruent trials. P1 was greater in LH than RH. P1 peaked early for contralateral cues
Carlson & Reinke	2010	Fearful and neutral faces backward masked	General *N* =12	F = 7 M = 5	Det	100%	33/100	0	NA	N170 face (150-190)	There was greater N170 amplitude contralateral to the fearful face. RVF cue had significantly greater amp in LH than LVF cue, LVF cue was greater (not significant) amp than RVF cue in the RH.
Eldar et al.	2010	Angry, happy, and neutral all open mouth	23 anxious and 23 non-anxious	Anxious F = 17 M = 6 Control F = 13 M = 10	Ori	100%	500	0	200	C1 face (60-105) P1 target (105-145) N1 face (148-203) P2 face 195-250)	Anxious group showed attention bias towards threat. Neither had attention bias towards happy. Anxious group had more negative C1 than non-anxious in angry. Anxious had greater P2 than non-anxious in both conditions.
Eldar & Bar-Haim	2010	Angry and neutral faces	Anxious = 30, non-anxious = 30	Anxious F = 26 M = 4 Control F = 22 M = 8	Ori	100%	500	0	100	P1 (90-140) N1 (140-190) P2 (190-270) N2 (250-330) P3 (330-400)	No P1. N1 decreased from pre to post regardless of group or training. Decreased P2 in anxious training and increase in anxious placebo. Anxious training had increased N2 and anxious placebo decreased. Decreased P3 in both non-anxious and anxious training. Increased P3 to target onset amplitude in incongruent conditions.
Fox et al.	2008	Happy, angry, and neutral faces	Anxiety HA *N* = 14 LA *N* = 14	F = 19 M = 9	Ori	16%	150	150 or 600	150	N2pc (170-220 and 225-270) P1 target (100-150)	There were no differences in N2pc for LA, but HA had enhanced N2pc to angry faces. In the short CTOA, P1 amplitudes were greater for angry-congruent compared to angry-incongruent, the opposite was trending in for happy.

Table 1 continued

Summary of included articles

Author	Year	Stimuli	Participants	Sex	Target task	% Resp	Stim (ms)	Delay (ms)	Probe (ms)	ERP Components (window in ms)	Findings
Helfinstein et al.	2008	Primed with social threat or neutral words, neutral and angry faces	Social anxious women *N* = 24, half high and half low	F = 24	Ori	100%	500	0	NA	P1 face (95-140) N1 face (155-200) P2 face (185-320)	In anxious individuals, prior stressors can modulate performance on the dot-probe task. When HAS were showed neutral prime words, they had attentional bias to threat but no attentional bias when primed with threat words. HAS group had larger P1 and smaller P2 than LSA. HSA trended towards Larger P2.
Holmes et al.	2009	Angry, happy, and neutral	General *N* = 17	F = 8 M = 9	Ori	100%	500	0	NA	N2pc face (180-250) Late N2pc face (250-320) SPCN face (320-500)	Angry-neutral faces had a more negative N2pc, late N2pc, and SPCN towards angry; whereas, happy-neutral only had more negativity in late N2pc and SPCN towards happy. Meaning angry faces rapidly capture and sustain attention, but happy has a slower capture of attention.
Holmes et al.	2014	Angry and neutral	General *N* = 22	F = 19 M = 18	Ori	100%	500	0	NA	N2pc face (180-252) Late N2pc face (252-320) SPCN face (320-500)	The researchers found that there was more negativity in early, late N2pc, and in SPCN towards angry faces during high WM load but no differences in low WM load. Responses were more accurate in low WM compared to high WM.
Liu et al.	2015	Disgust, angry, and neutral faces Chinese and foreign	General *N* = 60, half behavioral and half ERP	F = 30 M = 30	Det	10%	100	100-300	150	P1 Target (110-140) P3 target (450-650)	P1 had higher amplitudes for congruent angry than incongruent and lower amplitudes for disgust congruent when compared to incongruent. The P3 results showed that disgust congruent had higher amplitudes than angry congruent. Differences diminished when faces were foreign.
Mueller et al.	2008	Angry, positive, and neutral faces	Social anxiety *N* = 12, Control *N* = 15	SAD F = 8 M = 4 Control F = 7 M = 8	Ori	30%	100	100-300	NA	P1 face and probe (80-150)	The P1-face, SAD had greater amplitudes for angry-neutral trials than happy-neutral. Source localization indicated greater activity over middle and inferior temporal gyrus in SAD during angry-neutral vs happy neutral. In P1-probe, SAD had reduced amplitude for emotional congruent when compared to Controls.

Table 1 continued

Summary of included articles

Author	Year	Stimuli	Participants	Sex	Target task	% Resp	Stim (ms)	Delay (ms)	Probe (ms)	ERP Components (window in ms)	Findings
O'Toole & Dennis	2012	Angry and happy Faces	General AMB *N* = 49	F = 29 M = 20	Ori	100%	100 or 500	500	NA	P1 face and probe (120 and 140) N170 face (170) N1 probe (150-250) P2 face (230) N2 face (310) P3 face and probe (325-475)	ABM only effected a subset of participants on a behavioral level. The ERP correlation analysis revealed a correlation between greater P2 amplitude and smaller N170 to angry vs happy and attentional bias towards threat in the train towards threat group.
Osinsky et al.	2014	Angry and neutral	General Study 1 Control = 30 Train = 28; Study 2 Train = 36	Control F = 20 M = 8 Train F = 23 M = 7	Det and Ori	100%	500	0	NA	N2pc (180-300)	In study 1, there was more negative N2pc towards angry faces, the mean amplitude reduced across blocks though the difference remained the same. ABM had no effect on N2pc. Study 2 found similar results: that is no effect of ABM.
Pfabigan et al.	2014	Happy, angry, and neutral faces	General *N* = 21	F = 11 M = 10	Det	100%	500	0	3000	P1 probe (80-120)	Women had enhanced P1 amplitudes to happy congruent probes compared to men. No difference in angry faces. They also found that alexithymia was correlated with reduced P1 amplitudes in response to emotional faces.
Pourtois et al.	2005	Fearful, happy, and neutral	General *N* = 12	F = 9 M = 3	Ori	10%	100	100-300	150	P1 bar (120-160)	Greater global field power for P1 for fear congruent trials (not for happy). Source localization found that the enhanced P1 was related to activity in the extrastriate cortex for fear congruent trials. In addition, the posterior parietal and inferior temporal cortices had activity for fear congruent trials, whereas incongruent trials had activity in the medial frontal/anterior cingulate areas.
Pourtois et al.	2004	Fear, happy, and neutral faces	General ERP *N* = 6 Behave *N* = 16	ERP F = 5 M = 1 Behavioral F = 13 M = 3	Ori	10%	100	100-300	150	C1 face and bar (80-100) P1 face and bar (120-150) N1 bar (200-250) N170 (160-180)	In the time-locked to bar analysis P1 amplitude for fear congruent trials were greater than incongruent trials.

Table 1 continued

Summary of included articles

Author	Year	Stimuli	Participants	Sex	Target task	% Resp	Stim (ms)	Delay (ms)	Probe (ms)	ERP Components (window in ms)	Findings
Reutter et al.	2017	Angry and Neutral	Anxious correlation *N* = 94	F = 71 M = 23	Ori	100%	500	0	1000	N2pc (180-300)	No difference in RT between congruent and incongruent and there was no correlation between anxiety measures and RT. The N2pc indicated a bias towards angry facial expressions. They also found that higher scores on social anxiety (SIAS, not SPAI and SPS) correlated with more negative N2pc towards angry faces, even when controlling for trait anxiety.
Rossignol et al.	2013	Fear, disgust, happy, neutral faces	Social anxiety LSA = 13 HSA = 13	LSA F = 9 M = 4 HSA F = 11 M = 2	Ori	100%	500	200	200	P1 face and probe (100-160 and 100-200) N170 (160-240) P2 face (240-400)	Found no group differences in RT. In P1, LSA had greater amplitude in left hemisphere when disgust and fear were present; this was not seen in HSA. In N170, there was greater amplitude in left hemisphere when emotional face was in the RVF. HSA had greater P2 amplitude in neutral-angry in comparison to neutral-fear.
Santesso et al.	2008	Happy, angry, and neutral faces	General *N* = 16	F = 8 M = 8	Ori	30%	100	100-300	150	C1 face and target (50-80) P1 face and target (80-150) N170 face (130-210) N1 target (150-250)	Face-locked ERPs were not significant. Greater P1 amplitude for angry congruent than angry incongruent. Greater P1 amplitudes for RVF happy faces during incongruent trials, compared to happy congruent.
Suway et al.	2013	Angry and neutral faces	General Control = 15 Training = 12	F = 34	Ori	100%	500	0	200	P1 (80-130) N1 (115-165) P2 (125-225) P3 (285-400)	There were no group differences before training in RT or ERP. After training, the group trained to attend towards threat, had greater P2 amplitudes than the control group. The training group’s RT was also faster for congruent trials.
Yang et al.	2012	Aversive and neutral images IAPS for prime, Aversive and neutral faces for dot-probe	General *N* = 17	F = 9 M = 8	Ori	100%	500	0	1100	N1 (120-150) P2 (155-200)	More negative N1 and more positive P2 amplitudes were found when the faces were preceded by an aversive image.

Table 1 continued

Summary of included articles

Author	Year	Stimuli	Participants	Sex	Target task	% Resp	Stim (ms)	Delay (ms)	Probe (ms)	ERP Components (window in ms)	Findings
Zhang et al.	2016	Disgust, Angry, Fearful, Neutral, and Scrambled Faces; Backward masked	General *N* = 100	ERP F = 30 M = 30 Behavioral F = 20 M = 20	Det	10%	17/83	100-200	150	N1 target (160-200) P3 target (330-430)	N1 amplitudes reflected the behavioral data, that is, greater amplitudes when there were faster RTs. P3 amplitudes were greater for congruent trials than for incongruent trials.
Zhou et al.	2014	Angry, happy, neutral, Effects of escitalopram	Panic Disorder = 25 Controls = 25	Both groups F = 15 M = 10	Ori	100%	500	0	200	C1 (60-105)	At baseline, PD had more negative C1 amplitude than controls to angry-neutral. No C1 amplitude difference between groups after treatment.

Table 1: This table summarizes the articles included in the systematic review. Stimuli column identifies the type of facial expressions used. Participant column states the type of participants used (general is non-clinical or non-subclinical). In the sex column, F = female and M = male, ERP is the participants in the event-related potential experiment and B is the participants in the behavioral experiment. Target task column denotes the type of detection task used, Det = identify the location of the target (left or right) and Ori = discriminate the orientation of the target (e.g. horizontal or vertical bar). % Resp = percent of motor response required. Stim = how long the faces were displayed (17/83 and 33/100 were backward masked paradigms, initial face pair/masks). Delay = time between face offset and target onset. Probes = time target was presented.