THE ROLE OF ATTENTIONAL RESOURCES IN FACIAL EXPRESSION PROCESSING AMONG INDIVIDUALS WITH HIGH TRAIT ANXIETY: AN EVENT-RELATED POTENTIAL STUDY

by

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Abstract

Previous research highlights a relationship between anxiety and emotional facial expression processing, particularly for fear, but the nature of this relationship remains unclear. The current study aimed to understand a possible underlying factor of this relationship—specifically, the role of attentional resources was explored using event-related potentials (ERPs). Participants (N=67) were asked to identify target happy, fearful or neutral faces in a Rapid Serial Visual Presentation while ERPs and accuracy were recorded. Results suggest that such processing is largely affected by the degree of attentional resources available and by anxiety level, and are in line with the vigilance-avoidance hypothesis. Individuals with high anxiety showed an early perceptual bias to fearful faces followed by later cognitive avoidance, especially when attentional resources were limited. Results are discussed in terms of clinical interventions which might focus particularly on high pressure situations to anticipate and regulate this sensitivity to threat in highly anxious individuals.

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Table of Contents

List of Tables

List of Figures

The role of attentional resources in facial expression processing among individuals with high trait anxiety: An Event-Related Potential Study

Trait anxiety refers to an enduring aspect of an individual's personality that predisposes him or her to generally perceive situations as threatening (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). This enduring personality characteristic has consistently been shown to affect the processing of emotion-related stimuli (e.g. Avram, Baltes, Miclea & Miu, 2010; Chen, Lewin & Craske, 1996; Eldar, Yankelevitch, Lamy & Bar-Haim, 2010; Gray, Adams & Garner, 2009; Mogg & Marden, 1990; Rossignol, Philippot, Douilliez, Crommelinck & Campanella, 2005; Van Dam, Earleywine, & Altarriba, 2011). For example, Van Dam et al. (2011) showed that individuals with high anxiety were less accurate than those with low anxiety in naming the emotions that they were presented with (i.e. happy, fearful and neutral faces), in the order in which they were presented in a Rapid Serial Visual Presentation procedure. In another study, Avram et al. (2010) found that individuals with high anxiety were quicker to name fearful faces in an emotional face Stroop task than individuals with low anxiety. Similarly, Rossignol et al. (2005) found that individuals with high anxiety were faster to detect deviant emotional faces amongst neutral stimuli than those with low anxiety. Trait anxiety level has also been shown to modulate selection of emotional faces when presented in binocular rivalry (i.e. different faces presented to each eye), with elevated trait anxiety associated with an increased tendency to perceive angry and/or fearful faces and a reduced tendency to perceive happy faces (Gray et al., 2009). Taken together, these results suggest that there is a relationship between trait anxiety and processing of emotional faces, and particularly fear. The current study aimed at understanding possible underlining factors of this relationship. More precisely, the role of attentional resources in the link between anxiety and emotional facial expressions processing was explored in the current study. Previous research has argued that the differences in processing of emotional stimuli between individuals with high versus low anxiety may be related to attention (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Eldar et al., 2010; Sass et al., 2010). However, until now, no previous study had used event-related potentials to consider the role of attentional resources in this processing between individuals with differing levels of anxiety.

The Resource View of Attention

Attention can be defined as the mental energy or resource necessary for completing mental processes, which is believed to be limited in quantity and to be under the control of some executive control mechanism (Ashcraft & Klein, 2010). With that said, however, there are different connotations to the term *attention*- for instance, it can be used to refer to alertness and arousal, orienting and searching, and/or filtering and selecting. Furthermore, the term attention can be used to refer to mental resources and conscious processing (Kahneman, 1973). Notably, in previous studies which considered the effect of trait anxiety on the processing of emotional stimuli, attention has been defined in various ways. For instance, binocular rivalry studies define attention in terms of filtering and selecting, while studies which use an RSVP procedure rely on the orienting and searching definition of attention (Gray et al., 2009; Van Dam et al., 2011). Within the current study, attention will be defined in terms of mental resources and conscious processing (Kahneman, 1973).

When we refer to attention in this way, the notion that attention is a limited resource becomes more salient; that is, attention is the limited mental energy or resource that powers the mental system. Countless experiments have shown that there is a limit to how many different things we can attend to and do all at once (Broadbent, 1958; Moray, 1967). As a specific example of this, if an individual is required to process a target stimulus and then immediately process a second target stimulus, accuracy in identifying the second target declines because some of the resources needed to process it may still be operating on the first stimulus. That is, paying attention to the first stimulus deprives you of the attention needed to process the second stimulus. This effect is known as an 'attentional blink' (Raymond, Shapiro & Arnell, 1992). The current study ultimately used the attentional blink as a tool to actively deplete mental/ attentional resources and observe its impact on the processing of emotional faces.

Attentional Resources and Processing of Emotional Stimuli

It has been found, however, that in some cases when the first and second target images are positioned next to one another in the sequence, the attentional blink effect can be avoided; that is, the individual is able to process both targets (Visser, Bischof & Di Lollo, 1999). Luo et al., (2010) found that when individuals are asked to identify two target images that are presented rapidly amongst a sequence of distractor images, where the first target is a neutral stimulus (i.e. an image of a house) and the second target is an emotionally-charged stimulus (i.e. a fearful or happy face), they are able to accurately detect the second target (i.e. the emotional face) with ease, even when the two are positioned adjacent to one another in the sequence. Thus, the authors suggested that emotional stimuli may be immune to the attentional blink among individuals in general. This finding has been suggested to indicate that emotional stimuli are less subject to top-down attentional control; that is, they are processed automatically and do not require substantial attentional resources (see Fox, Russo & Georgiou, 2005 for review).

As mentioned, the role of attentional resources in the processing of emotional stimuli has been compared between individuals with high versus low levels of anxiety, in order to better understand how such individuals process emotional stimuli as well as how attention impacts this ability. Arend and Botella (2002) compared individuals with high trait anxiety to those with low trait anxiety on their ability to detect the only white word (i.e. target 1) presented amongst a stream of black words presented using an RSVP procedure and to detect if a probe word was present in the stream (i.e. target 2). The results showed that when a threatening emotional word (e.g. fear) was presented as the first target stimulus (i.e. the white word), the attentional blink effect was reduced among individuals with high anxiety compared to those with low anxiety (i.e. the second target stimulus—the probe—was processed with ease). In another study, Fox et al. (2005) compared individuals with high trait anxiety to individuals with low trait anxiety on their level of attentional blink when asked to identify an emotional face (i.e. fearful or happy face) that was positioned just after a neutral target (i.e. mushrooms or flowers). The results of these two studies showed that individuals with both high and low trait anxiety exhibited an attentional blink effect (i.e. they missed the second target stimulus) for fearful and happy faces. With that said, the magnitude of the attentional blink was attenuated for fearful faces among individuals with high anxiety. That is, they were able to detect the second target stimulus significantly more often than individuals with low anxiety. This suggests that while individuals with high anxiety may require fewer attentional resources to process threat-related stimuli than individuals with low anxiety, both groups nevertheless require these resources to some extent. These findings provide support for the conclusion that attentional resources are required for emotion perception and argue against claims that the processing of emotionally-charged stimuli is completely automatic. Thus the previous findings in this area are inconsistent.

Notably, this inconsistency may in part be related to how attentional resources were measured—that is, by relying on the participant's behavioural responses (i.e. his or her accuracy on the task). However, it has been suggested that this method is not always reliable (Dickinson &

Szeligo, 2008). For instance, it has been shown that participants' performance on a task (i.e. his or her behavioural responses) can be affected by multiple factors, two of which are the type of instruction provided for the task and the type of material presented in the task (Pachella & Pew, 1968; Peterson, Sandblom, Elfgren & Ingvar, 2003; Wells, 1993). Thus, the current study aimed to add to the previous research in this area by providing an additional method of monitoring attentional resources in the context of attentional blink observations in anxiety. Specifically, the current study used event-related potentials to better understand how attentional resources may underlie the link between trait anxiety and emotional facial processing.

Event-Related Potentials

In recent research, Event-Related Potentials (ERPs) have been used as a method of examining the relationship between anxiety and emotion recognition (Eldar et al., 2010; Holmes, Nielson & Green, 2008; Rossignol, Campanella, Bissot & Philippot, 2013; Sass et al., 2010). Monitoring ERPs allows the measurement of changes in the electrical activity occurring across the scalp in response to specific events. Consistent patterns of electrical activity occurring within a predictable time frame following the onset of a stimulus are known as ERP effects. Importantly for the current study, the use of ERPs offers an additional method of measuring attentional resources. Specifically, attentional resources have been shown to modulate the amplitude and latency of various ERP components (Luo et al., 2010). When an individual has access to more attentional resources during a given task, we typically see a larger amplitude and shorter latency of ERP components such as the P100. This larger amplitude and shorter latency is said to be reflective of greater or more facilitated processing of the stimulus. Notably, the reverse is also true: the fewer the attentional resources available to the individual, the smaller the amplitude and longer the latency, which indicates more shallow or deficient processing.

In addition, a purpose of the current research was to examine the 3-stage model of emotional facial expression processing proposed by Luo et al. (2010; discussed in more detail later), and more specifically, to determine if individuals with high trait anxiety follow the same pattern that was observed in a general sample of individuals. This examination is of importance as it may point out differences between individuals with high anxiety in comparison to those with low in terms of how they process emotional stimuli, and may thus have important clinical implications for how we can help such individuals. There are 6 ERP components that Luo et al. (2010) found to support this 3-stage model: the P100, N100, N170, VPP, N300 and P300. Importantly, these ERP effects have been compared between individuals with high and low anxiety while being presented with emotional faces and emotional words. For instance, the *P100* is a positive going waveform that occurs approximately 100 milliseconds post-stimulus onset and is thought to reflect the processing of the low-level features of stimuli, such as highly saturated colors (red, blue, green, yellow), colors indicative of skin tone, contrast, and distance or proximity to the target (Luo, Feng, He, Wang & Luo, 2010). Previous studies have shown individuals with high anxiety to have an enhanced P100 effect (i.e. a larger amplitude) when presented with emotionally-arousing stimuli, particularly threatening stimuli, as compared to individuals with low anxiety (Holmes et al., 2008; Rossignol et al., 2013; Sass et al., 2010). This finding has been suggested to represent an increased attentional vigilance—essentially, faster and earlier detection and allocation of attention—for such stimuli in individuals with high anxiety (Holmes et al., 2008; Sass et al., 2010).

Additionally, the *N170* is a negative-going waveform that occurs approximately 170 milliseconds post-stimulus onset and the *Vertex Positive Potential (VPP)* is the positive counterpart to the N170. These effects are said to be face-specific and to reflect the configural processing of facial stimuli (i.e. the processing of the spacing among features; in contrast to featural processing). These effects have been compared between high and low anxious participants in previous studies (e.g. Holmes et al., 2008; Rossignol et al., 2005). However, such studies have failed to show significant differences in the N170 and VPP across high and low anxious individuals, suggesting that individuals with high and low anxiety may not differ in their configural processing of faces.

The *P300* is thought to be part of an *attention-orienting complex* (Campanella, Caspard, Debatisse, Bruyer, Crommelinck & Guerit, 2002). More specifically, it is thought to reflect when a stimulus is detected as well as conscious decision-making and premotor response-related stages—that is, when an individual detects and attends to a stimulus, and then consciously decides what to do in response to that stimulus. Finally, the *N300*, which is thought to be particularly sensitive to emotional stimulation and reacts more to affective features of stimuli rather than to physical characteristics. Rossignol et al., (2005) found a reduced N300 in high anxious participants compared to low, suggesting that highly anxious individuals are less responsive to the emotional content of fearful and happy faces. However, the P300 component appeared significantly earlier in these highly anxious participants. The authors suggested that the earlier P300 may reflect an attempt to remedy the deficient emotional appraisal experienced by highly anxious individuals (which was evident by the reduced N300 amplitude). Specifically, the earlier P300 component suggests earlier orientation of attention and decision-making, and thus more salient conscious processing of the emotional content of these stimuli.

Taken together, the observed differences in accuracy, response time as well as ERP responses to emotional stimuli between individuals with high versus low anxiety provides sufficient evidence that individuals with high anxiety process emotional stimuli differently from those with low anxiety . Specifically, previous research appears to suggest that individuals with high levels of anxiety tend to show more facilitated processing of these stimuli, with faster reaction times as well as enhanced ERP amplitudes being reported. As mentioned, previous researchers have argued that this difference may be related to attention, in that individuals with differing levels of anxiety may devote different levels of attention to potentially threatening stimuli (Bar-Haim et al., 2007; Eldar et al., 2010; Sass et al., 2010).

Justification for the Current Study

The goal of the current study was to examine the role of attentional resources in the facial expression processing of individuals with high versus low levels of anxiety. The design of the current study replicated the previous design employed by Luo et al. (2010) in order to make comparisons between studies, but as mentioned, the current study added to the original study by comparing the performance of individuals with high and low trait anxiety. In Luo et al. (2010), participants were asked to identify target images that were presented in a Rapid Serial Visual Presentation (RSVP) procedure. Specifically, a series of 14 images were presented in rapid succession (i.e. 119 ms each), with two target images and 12 distractor images among them (See Figure 1). The first target image was one of three pictures of a neutral stimulus (i.e. a house), and this image appeared equally in the third, fourth or fifth position in the 14-image series. The second target image was one of three kinds of faces (happy, fearful or neutral), and this image appeared equally as often in the second or sixth position following the first target image. The first of two versions of the task served as a control measure, where participants were only asked questions about details of the second target image (i.e. the face), while in the second version participants were asked about both target images. The position of the second target image was manipulated to interfere with attentional processing resources, and more specifically, to facilitate an attentional blink effect. On some trials, the second target image appeared in the second position following the first target image. Here the individual has limited attentional resources to process the second target image (i.e. because they are attending to the first), and may report not seeing the image at all or may report inaccurate details about the image. On other trials, the second target image appeared in the sixth position following the first. Here the individual has more attentional resources and is thus able to report on the second target with more ease. That is, the individual has more time to process the first target image in full before being presented with the second target image, leaving his or her attention free to process the second target image later in the series.

As mentioned above briefly, the results of this study with a non clinical population showed that accuracy was better for fearful faces relative to happy and neutral faces, and that this accuracy was high regardless of available attentional resources. In other words, participants were able to correctly identify the second target when it was a fearful face even when it occurred directly following the first target image (i.e. during what should have been an attentional blink). In addition, they found that the availability of attentional resources had less of an effect on accuracy for happy faces than it did for neutral faces. That is, when the second target image was a happy face and was presented directly following the first target image, participants were better able to correctly identify it than they were when this second target was a neutral face. Based on these findings, Luo et al. (2010) concluded that substantial attentional resources are not required to process emotional stimuli, especially those that signal potential threat. However, based on the findings from Fox et al. (2005), it may prove beneficial to compare the performance of individuals with high and low trait anxiety using the same design as Luo et al. (2010) to test the validity of this conclusion. Specifically, it was shown that individuals with low trait anxiety do require substantial attentional resources to process emotional stimuli. Individuals with high anxiety, on the other hand, still require attentional resources, although they may require a less substantial amount than their low-anxiety counterparts. Thus, the first part of the current study was to determine if an attentional blink effect occurs among individuals with low and/or individuals with high trait anxiety when processing emotionally-charged stimuli. If this was the case, it would provide support against the claim by Luo et al. (2010) that attentional resources are not necessary for the processing of emotional faces in this context.

The second goal of the current study was to examine the ERP effects throughout this task, particularly to test the validity of the 3-stage model of facial expression processing proposed by Luo et al. (2010; see Table 1 for summary of model). The first stage of this proposed model involves the automatic processing of negative-valenced emotions (i.e. fear in this study). In terms of their ERP results, this stage was reflected by larger P100 and N100 amplitudes for fearful faces than for happy and neutral faces (with no difference between happy and neutral faces). That is, the negatively-valenced emotion (i.e. fear) was distinguished from other emotions. In the second stage, emotionally charged facial expressions (i.e. fearful and happy) are distinguished from neutral ones, but different emotions are not yet distinguished. This stage was reflected in this study by increased N170 and VPP amplitudes (corresponding to enhanced configural processing) for fearful and happy faces compared neutral faces, with no differences in amplitudes for fearful and happy faces. Finally, the third stage is where different emotional expressions are distinguished (i.e. fear is distinguished from happy). This was reflected by the finding of increased and P300 amplitudes, which corresponds to an increased processing of affective features (N300) and increased orientation of attention and conscious decision making (P300) for fearful faces compared to happy and neutral faces, as well as for happy faces compared to neutral faces. Notably, Luo et al. (2010) proposed this model based on theories and findings from a general sample of individuals. Given what we know about the impact of anxiety on these ERP components—with an enhanced P100 and reduced N300 amplitudes as well as an earlier P300 peak in high anxiety—it was important to consider whether the model would apply similarly to individuals with high versus low trait anxiety (Holmes et al., 2008; Rossignol et al., 2005; Rossignol et al., 2013; Sass et al., 2010). Specifically, this would help to determine if individuals with low or high trait anxiety process emotional facial expressions differently than a general (non-clinical) sample of individuals, which could have important implications for clinical interventions.

Research Questions

The current study compared the performance of individuals with high and low trait anxiety using the same design as Luo et al. (2010), which allowed the exploration of the impact of attentional resources on the ability to recognize emotional faces. Like the previous study, we examined accuracy on the task and monitored the P100, N100, N170, VPP, N300 and P300 ERP components. In doing so, we sought to address two major questions. First, are attentional resources important when participants are asked to identify emotional faces amongst a sequence of stimuli presented in rapid succession? Luo et al. (2010) concluded that substantial attentional resources are not required to process fearful and to a lesser extent happy faces. Comparing high and low anxious individuals on this same task serves as a tool to test this conclusion given that: previous research has shown an attentional blink effect—which is the result of a lack of attentional resources—for individuals with both high and low trait anxiety, and this effect was shown to be greater in individuals with low anxiety, suggesting that they require substantial attentional resources to process emotional stimuli (Fox et al., 2005). Thus, if the accuracy for detecting fearful, happy or neutral faces of individuals with high anxiety differed from that of low anxiety when attentional resources were manipulated, or if both groups showed an attentional blink effect, it would suggest that attentional resources are important in this context, and thus would argue against the conclusion made by Luo et al. (2010). On the other hand, if both individuals with high anxiety and individuals with low anxiety performed equally well on this task even when attentional resources were scarce (i.e. when an attentional blink effect should be present), it would provide support for the conclusion that substantial attentional resources are not required here. Similarly, measuring ERP activity also allowed us to monitor attentional resources in that larger amplitudes of the ERP components are typically seen when attentional resources are abundant. Thus, if individuals with high trait anxiety required fewer attentional resources to process fearful faces, this would be reflected not only by a decreased attentional blink effect, but larger ERP amplitudes when presented with a fearful face, regardless of whether or not it was positioned close to the other target image. Alternatively, if substantial attentional resources are required to process these stimuli, a strong attentional blink effect was expected to occur across groups which would be reflected by decreased amplitudes when target stimuli were positioned close together in the series, even if the target stimulus was a fearful face.

Second, does the pattern of ERP activity in individuals with high anxiety match the proposed 3-stage model of facial expression processing as proposed by Luo et al. (2010) for a general population? Again this 3-stage model suggests that negatively-valenced emotional stimuli are processed first, then emotionally-charged expressions are distinguished from neutral ones, and finally individual emotional expressions are distinguished from one another. Notably, if individuals with high anxiety showed an early attentional bias to emotionally charged stimuli in general and not just to threat-related stimuli (which would be reflected in the P100 amplitude), it would conflict with the first stage of the proposed model, which is supposed to reflect the automatic processing of negatively-valenced emotions only. On the other hand, the ERP components corresponding to the second stage of the model—the N170 and the VPP—have not yet been shown to differ between high and low anxious individuals, and thus we had no specific predictions or expectations regarding these ERP components in the current study. Finally, if differences were observed in the N300 and/or P300 across high and low anxious individuals—as they were in Rossignol et al. (2005; see above)—it may conflict with the third stage of the proposed model.

Thus, the current study was of value for two major reasons. First, by using the paradigm set by Luo et al. (2010) among individuals with varying levels of anxiety, it allowed testing of the idea that facial expression processing occurs in a predictable 3-stage process. More specifically, we were able to determine if this 3-stage model of facial processing would hold up among highly anxious individuals. Furthermore, by comparing individuals with high anxiety to individuals with low anxiety on both accuracy and ERP effects, we were able to test whether attentional resources are required when asked to recognize and identify fearful, happy and neutral faces while presented with an RSVP procedure in which attentional resources are manipulated.

Method

Participants

A total of 69 (11 Male) undergraduate students at Laurentian University were recruited for this study. Participants ranged in age from 17 to 51, with a mean age of 20.75 (SD=4.65). All participants were right-handed, had normal to corrected-normal vision, and had no history of neurological impairments that may affect the EEG reading. Based on scores from the State Trait Anxiety Inventory (STAI, Spielberger et al., 1983) and using the rule of thirds, participants were split into High (N=23), Medium (N=23) and Low (N=23) anxiety groups. The data from the group of individuals with medium levels of anxiety was removed prior to analyses, and the High Anxiety group was compared to the Low Anxiety group.

Materials

Anxiety. The State Trait Anxiety Inventory (STAI; Spielberger et al., 1983) was used to assess levels of state and trait anxiety. This is a 40-item self-report questionnaire, with 20 items assessing state anxiety (e.g. “I feel upset”; “I am worried”), and 20 items assessing trait anxiety (e.g. “I am calm, cool and collected”; “I am a steady person”). For the state anxiety items, participants are asked to indicate how they feel ‘right now, at the current moment’. Each of these items is rated on a 4-point scale (1= Not at all; 2= Somewhat; 3= Moderately so; 4= Very much so). For the trait anxiety items, participants are asked to indicate how they generally feel. Each of these items is also rated on a 4-point scale (1=Almost Never; 2= Somewhat; 3=Often; 4= Almost Always). The STAI is appropriate for individuals with a minimum grade 6 reading level. For the current study, participants in the lower third of scores were assigned to the Low Anxiety group (N=23; STAI scores ≤ 34) and those in the higher third of scores were assigned to the High Anxiety group (N=23; STAI scores ≥ 42). Results of an independent t-test revealed that the High and Low anxiety groups differed significantly on their total trait anxiety scores [$t(36.71)=16.33$, $p<.001$].

Experimental measure. Stimuli consisted of 60 face pictures and 3 upright house pictures. The facial stimuli were taken from the Karolinska Directed Emotional Faces (KDEF) inventory. Out of the 60 facial stimuli, 24 of these were inverted neutral faces which acted as distractor stimuli. The remaining 36 facial stimuli acted as the target stimuli and were made up of 3 different upright facial expressions acted out by 12 different individuals (i.e. each of the 12 actors showing happy, fearful and neutral facial expressions). Males and females were represented equally in all facial stimuli (i.e. 18 male target stimuli; 12 male distractor stimuli). Male distractor images were presented on trials in which target stimuli were male, and female distractor images were presented with female target stimuli. With that said, the order that the distractor images were presented was randomized throughout the experiment. All pictures were cropped into the shape of an ellipse, so that for the facial stimuli, only the individual's face was visible (i.e. not the hair or background of the image).

Procedure

Testing took place in a single session lasting approximately 2 hours. Participants were first asked to give informed consent, and then were asked to fill out a short demographics questionnaire (e.g. "Do you have a history of any neurological conditions"; "Are you taking any medications that may affect the ERP screening") and a handedness questionnaire ("Which hand do you use for each of these things: Writing, drawing, toothbrush", etc.). Participants were then fitted with the EEG cap and were seated in a sound proofed booth. Participants were then informed of the nature of the study verbally, the experimenter left the sound-proof booth and the experimental task was started.

The Rapid-Serial Visual Presentation paradigm chosen for the current study was modeled after Luo et al. (2010) and allows investigation of the attentional blink effect. Specifically, in the dual task mode of this paradigm, the onset of the second target (T2) comes approximately 200-500 milliseconds following the onset of the first target (T1), and the correct detection of T1 impedes the detection of T2.

The experiment was programmed using E-Prime (Version 2.0). At the beginning of the formal experiment, a white fixation point appeared in the center of the screen and remained for 500 milliseconds. The white fixation point was then replaced by a blue fixation point, which remained on the screen for 300 milliseconds and signalled the start of the trial. Following this, 14 images including both target and distractor images were presented rapidly in the center of the screen. Each image remained on the screen for a total of 119 milliseconds. The distractor images included 12 inverted neutral faces. The first target was one of three upright pictures of a house. The probability of the occurrence of each of these distractor images was the same. The second target stimulus was one of three types of faces: happy, fearful or neutral. Again, the probability of the occurrence of each facial expression was the same. The first target image appeared equally often in the third, fourth or fifth position of the 14-image series. The second target image appeared equally in the second (referred to as Lag2) or sixth (Lag6) position following the first target image. See Figure 1 for an example trial presentation. Additionally, there were two task modes: single and dual, which differed in terms of whether participants were asked about T1 and T2, or T2 only. Specifically, on single task trials, at the end of the 14-image series participants were asked if they saw a picture of a face and were required to respond with either yes or no. This task mode served as a control measure, where participants are only required to respond to the faces and not the houses, thus requiring fewer attentional resources. On dual task trials, however, participants were asked whether they saw a picture of a face (yes/no) and also whether they saw a picture of a house (yes/no). Participants were instructed to be as accurate as possible, and they were given an unlimited amount of time to respond on each trial. Following their response, participants were led to the next trial following a brief pause of 500 milliseconds.

Participants were presented with dual task and single task trials separately, with four blocks of each type containing 120 trials each. The blocks occurred at random, and participants were instructed which type of block they were entering prior to beginning each. Breaks were given at the end of each block, the length of which was determined by the participant. Baseline tasks were also designed based on the methods of previous studies (Luo et al., 2010; Vogel et al., 1998; Sergent et al., 2005). In these tasks, facial expressions at T2 were absent and replaced with a black and blank screen, with other conditions remaining unchanged. The study overall included 16 conditions: 4 conditions for the second target (happy face; fearful face; neutral face; T2 absent for baseline) by two lags (Lag2; Lag6) by two tasks (Single; Dual). Participants were presented with 60 trials for each condition, for a grand total of 960 trials.

ERP Acquisition and Analysis

A 64-electrode HydroCel Geodesic Sensor Net (Electrical Geodesics, Inc., Eugene, OR) was used to record data in conjunction with NetStation software, version 4.4.1 (Electrical Geodesics, Inc., Eugene, OR) and digitized with a sampling rate of 250 Hz. The vertex was used as the reference electrode, and the data was then re-referenced off-line to the average mastoid reference. The data was additionally filtered on-line using a 0.1 Hz high-pass filter, which was stored on a computer for off-line analysis. Next, the data was then filtered off-line using a 0.3-30 Hz band pass filter and segmented into 1200ms time-windows (epochs), which began 200ms before stimulus onset and extended 1000ms after the appearance of the stimulus. A threshold of 100μV was used to look for eye blink artifacts and a threshold of 5μV for horizontal eye movements. In order for a participant to be used in the data analysis, no more than 10% of the trials could be removed. An average was calculated for each participant, and epochs were baseline corrected using the 200ms interval before stimulus onset. Grand averages across all participants were then calculated for analysis.

In order to evaluate differences between individual components, the waveform was divided into specific time-windows (epochs): 80-150 ms, 100-170ms, 220-290ms, 230-290ms, 290-400ms, 475-550 ms. In addition, the averaged electrical activity across the different brain regions was examined as a function of montage channel groups. For instance, the 80-150 ms epoch represents the N100 component in the frontal montage (electrodes: 3, 6, 8, 9). Additionally, the 100-170 ms epoch represents the P100 component in the Occipital-Parietal (electrodes 33, 34, 36, 38). The 230-290ms epoch represented the VPP in the Frontal montage (3, 6, 8, 9), while the 220-290ms epoch represented the N170 in the Left-Temporal (30, 32) and Right-Temporal (44, 43) montages. Finally, the 290-440ms represented the N300 component in the Right Frontal (56, 58, 59) and Left Frontal (13, 18, 19), while the 475-550ms epoch represented the P300 in the Frontal montage (3, 6, 8, 9, 4, 7, 15, 16, 51, 53, 54).

While differences in activity was expected across regions of the brain, they are only relevant to the research question if they occur as a function of the stimulus condition, and are thus reflected in the interactions. Therefore, main effects for montage are not presented or discussed. All montages and epochs were selected upon visual inspection of collapsed grand average waveforms (Luck, 2014). More specifically, all target trials were combined into a single grand average waveform. Epochs were chosen by inspecting these collapsed waveforms, by selecting times that best represented a component. Montages were also selected using these collapsed waveforms, where montages were only selected if they contained the component in question. This method has been proposed by Luck (2014) to reduce bias when selecting component epochs, when dealing with a new experiment. In addition, the use of the montages rather than single electrodes is proposed to reduce noise (Luck, 2014).

Results

Accuracy

A 2 (Group; High Anxiety, Low Anxiety) x 2(Lag; Lag2, Lag6) x 2(Task; Single, Dual) x 4(Expression; Fearful, Happy, Neutral, Blank) mixed ANOVA was conducted to examine their effect on accuracy. According to Mauchly's test, sphericity was violated and thus Greenhouse Geisser values are reported where necessary. Mean accuracy scores by Group, Task, Expression and Lag are reported in Table 2. Results revealed a significant main effect of Task [F (1,44)= 49.13, p<.001, η^2_p = .53]. There was also a significant main effect for Lag [F(1,44)=57.46, p<.001, η^2_p =.57], but there was no significant effect for Expression [F(1.23,54.10)=3.37, p=.06, η^2_p =.07]. Results also revealed a significant interaction between Lag and Task [F(1,44)=30.61, p<.001, η^2_p = 0.41]. There was also a significant interaction between Lag and Expression [F(2.20,96.74)=22.122, p<.001]. None of the other interactions were significant, F(1,44) < 2.66, p > .06.

First, for the interaction between Lag and Task, follow-up paired t-tests collapsed across expression type revealed that accuracy was higher in the Lag6 condition than the Lag2 condition for both Single [t(45)=4.933,p<.001] and Dual [t(45)=7.76,p<.001] Task modes. Furthermore, accuracy was highest overall for the SingleLag6 condition [SingleLag6 > SingleLag2, t(45)=4.933,p<.001; DualLag6, t(45)=4.379,p<.001; and DualLag2, t(45)=8.274, p<.001] and lowest overall for the DualLag2 condition [DualLag2 < SingleLag6, t(45)=8.274, p<.001; SingleLag2, t(45)=8.194, p<.001; and DualLag6, t(45)=7.76, p<.001]. Second, for the interaction between Lag and Expression, follow up paired t-tests collapsed across Task revealed that accuracy was higher in the Lag 6 conditions than the Lag 2 conditions for Fearful [$t(45)=5.81$, $p<.001$], Happy [$t(45)=5.812$, $p<.001$] and Neutral expressions [$t(45)=7.75$, $p<.001$], but not for Blank expressions [$t(45)=1.693$, $p<.097$].

ERP

2(Lag) x 2(Task) x 3(Expression) x 2(Group) mixed ANOVAs were run for each of the six ERP components: the N100, P100, VPP, N170, N300 and P300. Blank conditions were not included in ERP analyses as the accuracy results showed no significant differences for these conditions, as well as to remain in line with ERP analyses conducted by Luo et al. (2010). For the N170 and N300 ERP components, separate analyses were performed for right and left electrode montages. Mean amplitudes for all ERP components as a function of Group, Task, Lag and Expression are reported in Table 3. See Figure 2 for waveforms comparisons by emotion for each group and condition. Sphericity was checked for all analyses, and Greenhouse Geisser values are reported where violations occurred.

N100

N100 amplitudes showed a significant main effect of Lag, $F(1,44)=18.608$, $p<.001$, $\eta^2_p=0.30$, with larger amplitudes for Lag 2 than Lag 6. The main effect for Task was not significant [$F(1,44)=0.61$, $p=.44$], and neither were the main effects for Expression [$F(2,88)=1.04$, $p=.36$] or Group [$F(1,44)=0.24$, $p=.63$]. None of interactions were significant, all Fs $(2,88) < 2.15$, $p > 0.12$. There was, however, a trend for the three-way interaction between Task x Expression x Group [$F(2,88)= 2.65$, $p=.077$, $\eta^2_p=0.06$].

Because of the relevance of this trend for the current field as well as the practice of examining trend in ERP research (Luck, 2014), we conducted follow-up tests to explore this trend. Follow-up LSD pairwise comparisons revealed larger N100 amplitudes for fearful faces than both happy ($p=.053$) and neutral ($p<.04$) faces, but only for the high anxiety group, and only within the dual task [High, Single Task: Fearful vs. Happy, $p=.65$, Fearful vs Neutral, $p=.76$; Low, Dual Task: Fearful vs Happy, $p=.59$, Fearful vs Neutral, $p=.33$; Low, Single Task: Fearful vs. Happy, $p=.47$, Fearful vs Neutral, $p=.25$].

P100

Examination of the P100 amplitudes revealed no significant main effects for Task [$F(1,44)=1.17$, $p=0.28$], Lag [$F(1,44)= 0.08$, $p=0.78$], Expression [$F(2,88)=0.53$, $p=0.59$] or Group [$F(1,44)=0.05$, $p=0.83$]. There was a significant interaction between Lag and Group [$F(1,44)=4.61$, $p<0.04$, $\eta^2_p=0.095$] as well as a trend for the interaction between Lag and Expression [$F(2,88)=3.00$, $p=0.055$, $\eta^2_p=0.064$]. All other interactions were not significant [all Fs$(2,88)< 1.5$, $p>.23$].

Analysis of the simple effects of Group as a function of Lag revealed that the interaction is being driven by higher P100 amplitudes among the High Anxiety group than Low for Lag 6 ($p=.069$). There were no significant differences between groups for Lag 2 ($p=.25$). The simple main effects of Lag as a function of Group revealed no significant differences between lags for high anxiety ($p=.093$) or low anxiety ($p=.194$). Follow-up tests were again carried out for the statistical trend (Luck, 2014). LSD pairwise comparisons for the simple effects of Expression as a function of Lag revealed higher P100 amplitudes for neutral faces than happy faces for Lag 6 ($p<.03$), but not for Lag 2 ($p=.596$). All other differences of Expression as a function of Lag were not significant: fearful versus happy at Lag2 ($p=.44$), fearful versus neutral at Lag2 ($p=.81$), fearful versus happy at Lag6 ($p=.18$), and fearful versus neutral at Lag6 ($p=.45$). Tests of the simple effects of Lag as a function of expression were not significant [Happy: p=.38, Fearful: p=.50, Neutral: p=.30].

N170 – Right Temporal

N170 amplitudes in the right temporal montage revealed a significant main effect of Task [F(1,44)=10.83, p<.003, η^2_p =.20], with larger N170 amplitudes in the Single task than the Dual task. There was also a significant main effect of Lag [F(1,44)=43.50, p<.001, η^2_p =.50], with larger N170 amplitudes for Lag2 than Lag6. The main effect of Expression was also significant [F(2,88)=9.79, p<.001, η^2_p =.18], but the main effect of group was not [F(1,44)=0.25, p=0.62]. There was also a significant interaction between Expression and Group [F(2,88)=3.37, p<0.04]. No other significant interactions were found [all Fs (2,88) <1.35, p>.25].

Tests of the simple effects of Expression as a function of Group using LSD pairwise comparisons revealed that while both high (p<.002) and low (p<.03) anxiety groups showed larger N170 amplitudes for happy than neutral faces, the high anxiety group also showed significantly larger N170 amplitudes for happy faces than fearful faces (p<.001), which was not seen in low anxiety (p=.53). There were no significant differences between amplitudes for fearful and neutral faces for either group (Low: p=.18, High: p=.39). Tests of the simple effects of Group as a function of Expression revealed no significant differences [Fearful: p=.88; Happy: p=.33; Neutral: p=.54].

N170 Left Temporal

N170 amplitudes in the left temporal montage revealed a significant main effect of Task [F(1,44)=4.96, p<.04, η^2_p =.10], with larger N170 amplitudes in the Single task than the Dual task. There was also a significant main effect of Lag [F(1,44)=16.66, p<.001, η^2_p =.26], with larger N170 amplitudes for Lag2 than Lag6. There were no significant main effects of

Expression [$F(1.62,71.27)=1.78$, $p=.18$] or Group[$F(1,44)=0.73$, $p=.40$]. There was a significant interaction between Task and Expression [$F(2,88)=6.36$, $p<.004$, $\eta^2_p = .13$], as well as between Lag and Expression [$F(2,88)=4.03$, $p<.03$, $\eta^2_p =.08$]. No other significant interactions were found [all Fs $(2,88) < 1.48$, $p > .23$].

For the interaction between Task and Expression, LSD pairwise comparisons were used to examine the simple effects of Expression as a function of Task. Results revealed significantly larger N170 amplitudes for neutral faces than both fearful ($p<.01$) and happy ($p<.01$) faces, but only in the dual task mode [Single Task: neutral versus fearful ($p=0.31$), neutral versus happy ($p=.50$)]. There were no significant differences between fearful and happy faces in either the Single Task ($p=.75$) or the Dual Task ($p=.70$). Tests of the simple effects of Task as a function of Expression showed significantly larger amplitudes for neutral faces in the Single task than in the Dual Task ($p<.001$). No significant differences were observed for happy or fearful faces between Single and Dual tasks (Happy: $p=.76$; Fearful: $p=.67$)

For the interaction between Expression and Lag, tests of the simple effects of Expression as a function of Lag were examined using LSD pairwise comparisons. Results revealed significantly larger N170 amplitudes for fearful faces than neutral faces for Lag2 ($p<.03$) but not for Lag6 ($p=.79$), as well as for happy faces over neutral faces in Lag 2 ($p<.01$) but not in Lag6 ($p=.75$). There were no significant differences between fearful and happy faces in either Lag2 ($p=.42$) or Lag6 ($p=.97$). Tests of the simple effects of Lag as a function of Expression revealed larger amplitudes for Lag 2 than Lag 6 for all expressions [Happy: $p<.001$; Fearful: $p<.002$; Neutral: $p<.006$].

VPP

Analysis of the VPP amplitudes revealed a significant main effect of Task [$F(1,44)=23.12$, $p<.001$, $\eta^2_p=.34$], with larger VPP amplitudes for the Single task than the Dual task, as well as a significant main effect of Lag [$F(1,44)=123.004$, $p<.001$, $\eta^2_p=.74$], with larger amplitudes for Lag2 than Lag 6. There was also a significant main effect of Expression [$F(1.74,76.52)=21.26$, $p<.001$, $\eta^2_p=0.33$. LSD pairwise comparisons revealed larger VPP amplitudes for happy faces than both fearful ($p<.001$) and neutral ($p<.001$) faces, but no significant differences in amplitude between fearful and neutral faces ($p=.91$). The main effect of group was not significant, [$F(1,44)=0.54$, $p=.47$]. A significant interaction between Task and Lag was observed [$F(1,44)=14.38$, $p<.001$, $\eta^2_p=.25$]. No other significant interactions were found [all Fs $(2,88) < 2.10$, $p > 0.14$].

Tests of the simple effects of Lag as a function of Task using LSD comparisons revealed larger VPP amplitudes for Lag2 than Lag6 for both the single ($p<.001$) and dual ($p<.001$) tasks. Tests of the simple effects of Task as a function of Lag showed significantly larger VPP amplitudes for the Single task than the Dual task for Lag2 ($p<.001$), but not for Lag6 ($p=.32$).

N300 Right

Analysis of the N300 amplitudes in the right electrode montage revealed a significant main effect of Lag [$F(1,44)=142.33$, $p<.001$, $\eta^2_p=0.76$], with larger N300 amplitudes for Lag2 than Lag 6. There was no significant main effect of Task [$F(1,44)=0.04$, $p=.84$], Expression [$F(2,88)=0.42$, $p=.66$] or Group [$F(1,44)=0.07$, $p=.80$]. There was a significant interaction between Task, Expression and Group [$F(2,88)=3.34$, $p<.05$, $\eta^2_p=.07$]. No other significant interactions were found [all Fs $(2,88) < 1.9$, $p > 0.18$].

Follow-up LSD pairwise comparisons to examine the simple effects of expression revealed that the significant three-way interaction is driven by larger N300 amplitudes for fearful than neutral faces for the high anxiety group in the single task mode (p=.084). Tests of the simple effects of Task revealed significantly larger amplitudes for the single task than the dual task for fearful faces within the high anxiety group (p<.04), which was not seen for the low anxiety group (p=.15).

N300 Left

Analysis of the N300 amplitudes in the left electrode montage revealed a significant main effect of Lag [F(1,44)=181.19, p<.001, η^2_p =.81], with larger N300 amplitudes for the Lag2 condition than the Lag6 condition. There were no significant main effects of Task [F(1,44)=1.67, p=.20], Expression [F(2,88)=2.44, p=.09] or Group [F(1,44)=0.18, p=.68]. There was a significant interaction between Task and Lag [F(1,44)=4.91, p<.04, η^2_p =.10]. There was also a statistical trend for the interaction between Task and Group [F(1,44)=3.87, p=.055, η^2_p = 0.08]. There were no other significant interactions [all Fs (2,88) < 2.12, p > .13].

For the interaction between Task and Lag, tests of the simple main effects of Task as a function of Lag were examined using LSD pairwise comparisons. Results showed significantly larger N300 amplitudes for the Single Task than the Dual task, but only in the Lag2 condition (Lag2: p<.04, Lag6: p=.65). Tests of the simple main effects of Lag as a function of Task showed significantly larger N300 amplitudes for Lag2 than Lag6 in both the Single (p<.001) and Dual (p<.001) task modes. The statistical trend (between Task and Group) was again followed up with LSD pairwise comparisons (Luck, 2014). Tests of the simple main effects of Task as a function of Group revealed larger N300 amplitudes for Single Task than Dual Task for the high anxiety group (p<.03), but not for the low anxiety group (p=.63). There were no significant differences between groups as a function of Task (Single: p=.41, Dual: p=.97).

P300

The results of the analysis of the P300 amplitude showed a significant main effect of Lag [F(1,44)=169.49, p<.001, η^2_p =.79], with larger amplitudes for Lag2 than Lag6. No other main effects were significant: Task [F(1,44)=1.38, p=.25], Expression [F(2,88)=0.46, p=0.64], Group [F(1,44)=0.20, p=.66]. There was a significant interaction between Task, Lag and Group [F(1,44)=5.83, p<.03, η^2_p =.12]. No other interactions were significant [all Fs (2,88) < 1.83, p >.17].

Follow-up pairwise comparisons for the simple effects of Lag revealed larger amplitudes for Lag2 than Lag6 for all conditions: Single Task for low anxiety (p<0.001), Dual task for low anxiety (p<0.001), Single task for high anxiety (p<0.001), and Single task for low anxiety (p<0.001). With that said, in Task 2, there is a larger difference across lags in the low anxiety group (M_d = 4.24) than in the high anxiety group (M_d =3.22).

Discussion

The goal of the current study was to explore the role of attentional resources in the relationship between trait anxiety and the processing of emotional stimuli. Specifically, accuracy in identifying target images amongst a rapid stream of images was examined, and event-related potential amplitudes were examined throughout this task to determine whether substantial attentional resources are required to process emotional faces among individuals with high versus low anxiety. The study also sought to test the 3-stage model of emotional facial processing proposed by Luo et al. (2010). This model proposes an initial stage where negatively-valenced faces (e.g. fearful faces) are automatically processed and distinguished from all others, then a second stage where emotionally charged facial expressions (e.g. fearful and happy faces) are distinguished from neutral ones, and finally the third and final stage where individual facial expressions are distinguished from one another (i.e. fearful distinguished from happy and neutral; happy distinguished from neutral). In particular, the current study explored whether this 3-stage model applies to individuals with high and low levels of trait anxiety. Results in regard to this model were mixed and will be discussed at length below.

Accuracy Results

Accuracy results revealed that attentional resources were successfully manipulated using the RSVP presentation, where images are presented in rapid succession (i.e. 110 ms each) with target images presented amongst a stream of distractor images, and the position of the second target image relative to the first being manipulated to interfere with available attentional resources. The successful manipulation was evidenced by the strong attentional blink effect seen across participants, where participants were more likely to 'miss' a target image when it was presented adjacent to another target image (i.e. where they have limited attentional resources to process it). That is, regardless of anxiety level and regardless of the emotional face presented, participants were less accurate in identifying the second target image (i.e. the happy, fearful or neutral face) in Lag2 conditions when it was presented very close in time to the first target image (i.e. the house), in comparison to Lag6 conditions when target images were spaced farther apart. Accuracy was especially impaired for Lag2 conditions in the Dual Task mode, where participants were asked to look for both images, in comparison to the Single Task mode where they were only required to look for second target (i.e. the face). These results were expected, as the former condition is especially taxing on the participant's attentional resources and is thus more challenging and more likely to result in errors. Further, these results are in line with Luo et al. (2010) on which the current study was based, and imply that attentional resources have a significant impact on an individual's ability to process images in rapid succession.

With that said, however, Luo et al. (2010) found that this finding was moderated by the emotional nature of the images that were presented, which was not supported by the current study. As mentioned, the results of the current study showed that regardless of the emotional nature of the face presented (i.e. happy, fearful or neutral), individuals were less able to accurately detect such faces when they were presented in the Lag2 condition (i.e. adjacent to the first target image). In other words, the emotional nature of the face did not aid participants in the task when attentional resources were scarce. This is in direct contrast to the results of Luo et al. (2010) who found that accuracy was better for fearful faces relative to happy and neutral faces, and that this accuracy was high regardless of the availability of attentional resources. The results of the current study appear to counter the conclusion of Luo et al. (2010) that emotional stimuli are immune to the attentional blink, and instead suggest that attentional resources are required to process these stimuli. These findings are important in that they suggest that we do not process emotional information automatically, and instead, processing of such information is conscious and requires cognitive effort.

Furthermore, the current study sought to determine if the attentional blink effect would differ as a function of anxiety. Accuracy results suggest that this is not the case, with the attentional blink effect occurring across participants, regardless of anxiety level. Of note, this finding opposes results from Arend and Botella (2002) and Fox et al. (2005) who found that the magnitude of the attentional blink was attenuated for fearful faces among individuals with high anxiety. Thus, unlike previous conclusions (Arend & Botella, 2002; Fox et al., 2005), accuracy results from the current study suggest that individuals, regardless of anxiety level, require attentional resources to process threat-related stimuli, and when those resources are maxed, the ability to recognize such stimuli declines. With that said, however, the current study was unique in this area in that it offered an additional method of monitoring these effects; namely, the use of event-related potentials. This more sensitive method revealed subtle neurophysiological differences between anxiety groups on the current task.

ERP results

In general, ERP results revealed larger amplitudes for the Single task, where participants are instructed to look for the face only, in comparison to the Dual task, where they are instructed to look for both the house and the face. In other words, larger ERP amplitudes in this case were associated with less cognitive demand and increased attentional resources, which is in line with the previous findings from Luo et al. (2010). With that said, however, the current study also found increased ERP amplitudes for the Lag2 condition than the Lag6 condition, which is in direct opposition to the findings from Luo et al. (2010). In the current study, larger amplitudes were observed when the second target image was presented close to the first target image, even though attentional resources are limited and accuracy was lower for these conditions. These results were surprising given the previous findings from Luo et al. (2010) that larger amplitudes are associated with greater or more facilitated processing.

However, previous literature has suggested that larger ERP amplitudes may also be associated with increased cognitive effort to complete the assigned task (e.g. Si, Xu, Feng, Xu & Zhou, 2014; Ullsperger, Metz & Gille, 1988). In the current study, Lag2 conditions are significantly more difficult than Lag6 conditions, given the increased cognitive demand and limited attentional resources at the participants' disposal (i.e. because the two target images are presented adjacent to one another in the Lag2 conditions). Accuracy results reflected this difficulty, with participants being most likely to make errors on these types of trials. With that said, however, accuracy overall was still high—with the lowest accuracy on the task in general being 80% for the Lag2 condition within the Dual task mode. Thus it could be hypothesized that such trials, being more difficult, require increased mental effort to maintain this high level of accuracy, in comparison to the other less challenging trials (e.g. the Lag6 condition where the individual has more time to process each target image). With that said, further exploration in this area is needed given the mixed results between the current study and the former study by Luo et al. (2010).

Furthermore, ERP results from the current study point to subtle differences between individuals with high versus low trait anxiety. Of note, the current study did not find differences in the P100 or the N300 between individuals with high versus low anxiety. This is in contrast to previous research showing enhanced P100 amplitudes and reduced N300 amplitudes among individuals with high anxiety compared to those with low (Holmes et al., 2008; Rossignol et al., 2013, Sass et al., 2010). However, the current study did find that individuals with high anxiety showed larger N100 amplitudes for fearful faces than both happy and neutral faces when attentional resources were scarce (i.e. in the dual task mode), a finding which was not observed among individuals with low anxiety. Additionally, contrary to previous research which showed no differences between high and low anxiety on the N170 component (e.g. Holmes et al., 2008; Rossignol et al., 2005), the current study did detect differences here. While all participants in the current study (regardless of anxiety level) showed larger N170 amplitudes for happy faces over neutral faces, individuals with high anxiety also showed larger N170 amplitudes for happy faces over fearful faces, which was not observed among individuals with low anxiety. Taken together, these results suggest that individuals with high trait anxiety may show an early perceptual bias to threatening stimuli (i.e. fearful faces; reflected by the N100). However, later when cognitive processing comes into play (reflected by the N170 component), such individuals may avoid these threatening stimuli, which is reflected by decreased ERP amplitudes. Instead, such individuals may then favor non-threatening, positive stimuli (i.e. happy faces), as reflected by the increased amplitudes for these stimuli.

These results are in line with the vigilance-avoidance hypothesis (Mogg, Bradley, Miles & Dixon, 2004), which argues that anxiety-related attentional biases vary over time, and that individuals with high trait anxiety will engage in a cognitive avoidance strategy following initial vigilance. Of note, this cognitive avoidance is thought to be especially likely if the stimulus is appraised by the individual as ‘minimally threatening’ following initial vigilance, as would arguably be the case in the current study given the minimal threat of the briefly presented fearful face (Mogg et al., 2004). Additionally, previous research has suggested that this cognitive avoidance strategy may be used in order to reduce the emotional impact of the threatening stimulus (de Ruiter and Brosschot, 1994; Holmes, Nielson & Green, 2008; Stormark & Hugdahl, 1996). Therefore, while individuals with high anxiety may have an automatic tendency to be oriented to threatening stimuli, they may have also developed strategies to regulate their emotional reaction and to prevent this sensitivity from having lasting negative effects—namely, by avoiding this stimulus in favor of more positive or neutral stimuli. This finding has important clinical implications, as it suggests that individuals with high anxiety have the capacity to avoid threatening stimuli, and thus may be capable of engaging in self regulation. Furthermore, this finding suggests that training such individuals to maximize this skill would be of benefit in terms of preventing long term negative reactions to threat.

Furthermore, results suggest that this cognitive avoidance strategy is only used among individuals with high trait anxiety when attentional resources are limited. Specifically, the current study found that in the Single task mode when attentional resources were abundant (i.e.

participants were instructed to only look for the face images), individuals with high anxiety showed larger N300 amplitudes for fearful faces than neutral faces. Thus, the bias toward threatening stimuli holds throughout early and later processing stages (i.e. from early ERP components like the N100 to later like the N300) when attentional resources are unlimited. This suggests that the added pressure of the Dual task encourages individuals with high levels of anxiety to initiate the cognitive avoidance strategy. Furthermore, these results ultimately highlight the important role attentional resources play in the processing of emotional stimuli among individuals with high trait anxiety. These results have important practical implications in that they suggest that individuals with high anxiety are most likely to be sensitive to threat when they are in a more demanding or even stressful situation. Thus this finding implies that clinical interventions should focus on training such individuals to cope with threat when attentional resources are maxed, in order to decrease heightened anxiety in such situations.

3 Stage Model of Emotional Facial Expression Processing

A second goal of the current study was to test the 3-stage model of emotional facial expression processing proposed by Luo et al. (2010) among our sample of high versus low trait anxious individuals. Stage one of the proposed model was said to represent the automatic processing of negatively valenced emotions, and was reflected by larger N100 and P100 amplitudes for fearful faces than both happy and neutral faces, with no differences between happy and neutral faces (Luo et al., 2010). As mentioned, this early orientation to threat was partially supported by the current study, particularly for individuals with high trait anxiety. Such individuals showed larger N100 amplitudes for fearful faces than both happy and neutral faces, with no significant differences between happy and neutral faces. However, this was not observed among individuals with low anxiety. Also, contrary to the findings of Luo et al. (2010), there were no differences in the P100 amplitudes as a function of expression in the current study. These findings appear to support the notion that high levels of anxiety in general correspond to an automatic sensitivity to threat, which is in line with the vigilance-avoidance hypothesis described above (Mogg et al., 2004). Furthermore, results emphasize that this sensitivity is unique to high trait anxiety, unlike the finding from Luo et al. (2010), which suggested that the sensitivity occurs among individuals in general (regardless of anxiety level). Of note, both the current study and the previous study by Mogg et al. (2004) compared high and low levels of anxiety, while the previous study by Luo et al. (2010) did not, which may account for these discrepant findings. Future studies should thus continue to examine the effects of anxiety in the context of emotional facial expression processing to resolve these inconsistent results.

The second stage of the model proposed by Luo et al. (2010) was said to represent the distinguishing of emotionally charged facial expressions from neutral expressions, and was reflected by larger N170 and VPP amplitudes for fearful and happy expressions over neutral expressions, with no differences between fearful and happy expressions. Again, this finding was partially supported by the current study, with larger N170 amplitudes in the left hemisphere for fearful and happy faces over neutral faces and no significant differences between fearful and happy faces. Notably, this finding occurred across participants, regardless of anxiety level. However, contrary to the previous study, this effect did not occur across conditions, and the availability of attentional resources was critical in the outcome of the ERP effects. Specifically, the aforementioned pattern was only observed when attentional resources were scarce (i.e. in the Lag2 condition but not in the Lag6 condition). Additionally, a different pattern emerged for the N170 amplitudes in the right hemisphere, with larger amplitudes for happy faces over fearful faces, and no differences between fearful and neutral or between happy and neutral faces.

Furthermore, this pattern was only observed among participants with high anxiety, while there were no differences in right-hemispheric N170 amplitudes across emotions for participants with low anxiety. For the VPP component, the current study again showed a different pattern of results than those observed by Luo et al. (2010), with larger VPP amplitudes for happy faces than both fearful and neutral faces, but no significant differences between fearful and neutral faces. Taken together, these results suggest that while the second stage of processing may be important for distinguishing happy faces from neutral faces as argued by Luo et al. (2010), it may be less so for distinguishing fearful faces. Furthermore, these results emphasize that processing is significantly impacted by the amount of attentional resources at the participant's disposal as well as his or her anxiety level, and also that this middle stage of processing differs as a function of brain hemisphere. This suggests that emotional facial processing is complex and is largely impacted by attentional resources as well as anxiety. Thus models of emotional facial expression processing should take these variables into account. Furthermore, from a clinical perspective, it highlights the importance of anticipating different and unique responses and/or sensitivities to emotional stimuli among individuals with high levels of anxiety in order to best assist such individuals in improving their emotional reactions.

The final stage of the proposed model by Luo et al. (2010) was said to represent the distinguishing of individual emotional expressions (i.e. happy, fearful and neutral expressions are all labelled and distinguished from one another), and was reflected by larger N300 and P300 amplitudes for fearful faces over happy and neutral faces, and for happy faces over neutral faces. The results of the current study again only partially support this stage, with larger N300 amplitudes in the right hemisphere for fearful than neutral faces. However, unlike the previous study, there were no differences between happy faces and fearful faces, or between happy faces and neutral faces. Furthermore, the aforementioned difference in amplitude did not occur in the left hemisphere, and was only observed within the high anxiety group when cognitive demand was low and attentional resources were abundant (i.e. in the Single task mode). Furthermore, there were no differences in the P300 amplitude as a function of expression in the current study, contrary to those observed by Luo et al. (2010). Thus, results from the current study suggest that this stage of processing may not be particularly important for distinguishing between different facial expressions, as proposed by Luo et al. (2010). Moreover, these results again support the finding that attentional resources and anxiety are important moderators of emotional facial expression processing and should thus be included in models such as these.

In general, the results of the current study, which used differences in anxiety as a tool to test the accuracy and generalizability of the 3-stage model of facial expression processing, suggest that this model may be more complex than originally proposed, and may require modifications. Specifically, our results highlight that the processing of emotional facial expressions may not occur in a predictable three-stage pattern across individuals, as predicted by Luo et al. (2010). Further, such processing appears to be significantly impacted by other factors—namely, the amount of attentional resources at one’s disposal as well as trait anxiety level. The early sensitivity to fearful faces (i.e. stage 1), as well as the later orientation to happy faces (i.e. stage 2) proposed by the original model were supported by the current study, but they were only present among individuals with high levels of anxiety. While trait anxiety was not examined in the previous study by Luo et al. (2010), it could be hypothesized that participants in that study had higher levels of trait anxiety than the general population, thus accounting for the early sensitivity to threat followed by later orientation to other emotional expressions (i.e. happy and neutral expressions) seen among their participants. Regardless, the results of the current study ultimately point to the vigilance-avoidance hypothesis as an explanation for emotional facial processing among individuals with high trait anxiety, and suggest that further research may be needed to determine how such processing occurs among populations with low to moderate levels of anxiety.

Limitations and Future Directions

One potential limitation to the current study is that we tested participants with a non-clinical measure of anxiety (i.e. trait anxiety which is an enduring personality characteristic and not a clinical diagnosis), and thus the generalizability of these results to clinical populations may be limited. Furthermore, the trait anxiety scores from the STAI (Spielberger et al., 1983) in the current study were not severely elevated; the maximum trait anxiety score on the STAI is 80, while in the current sample the maximum trait anxiety score was 60. Thus, it cannot be said that individuals from the high anxiety group in the current study had severe levels of anxiety. However, individuals in the high anxiety group did have significantly higher anxiety scores than those in the low anxiety group ($p<.001$), and thus differences in accuracy and ERP effects across groups can be considered to be due to differences in anxiety. With that said, future studies should consider clinical levels of anxiety to determine if similar results to the current study are observed when anxiety is more severe (e.g. among individuals diagnosed with an anxiety disorder such as Generalized Anxiety Disorder). Additionally, the analyses of the current study did not include the group of individuals with moderate levels of anxiety. Thus future studies should consider this group, specifically to determine how moderate levels of trait anxiety might impact the processing of emotional facial expressions, as well as to make comparisons between this group and those with high and low levels of anxiety.

Conclusion

Overall, the results of the current study support the relationship between anxiety and emotional facial expression processing. More specifically, they suggest that emotional facial expression processing is largely affected by the degree of attentional resources available and by anxiety level, and is perhaps more complex and less predictable than previously thought. Furthermore, the findings of the current study argue for an early perceptual vigilance to threatening stimuli followed by cognitive avoidance of such threat among individuals with high trait anxiety, particularly when task demands are high and attentional resources are scarce. Following from these results, it is suggested that interventions for individuals with high levels of anxiety should particularly focus on strategies for regulating emotional reactions in high-pressure or demanding situations where attentional resources may be maxed, in order to anticipate and account for, or even prevent the automatic sensitivity or bias to threat among such individuals.

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Table 1. Summary of 3-stage model of emotional facial processing

Stage	ERP correlates	Amplitude differences
Stage 1 Automatic processing of negative-valenced emotions	P100 N100	Fearful > Happy and Neutral
Stage 2 Emotionally charged facial expressions are distinguished from neutral ones	N170 VPP	Fearful and Happy> Neutral
Stage 3 Individual emotional expressions are distinguished	N300 P300	Fearful > Happy > Neutral

Table 2. Mean accuracy by Group, Task, Expression and Lag.

	Sing Lag2 F	Sing Lag2 H	Sing Lag2 N	Sing Lag2 B	Sing Lag6 F	Sing Lag6 H	Sing Lag6 N	Sing Lag6 B	Dual Lag2 F	Dual Lag2 H	Dual Lag2 N	Dual Lag2 B	Dual Lag6 F	Dual Lag6 H	Dual Lag6 N	Dual Lag6 B
Low anxiety	0.93 (0.13)	0.95 (0.07)	0.91 (0.13)	0.96 (0.06)	0.95 (0.12)	0.96 (0.09)	0.95 (0.11)	0.96 (0.05)	0.88 (0.16)	0.87 (0.14)	0.83 (0.16)	0.90 (0.10)	0.94 (0.12)	0.94 (0.12)	0.92 (0.15)	0.91 (0.12)
High Anxiety	0.94 (0.09)	0.94 (0.07)	0.89 (0.11)	0.93 (0.07)	0.96 (0.06)	0.97 (0.04)	0.95 (0.06)	0.93 (0.09)	0.86 (0.12)	0.86 (0.14)	0.80 (0.19)	0.87 (0.14)	0.93 (0.10)	0.92 (0.11)	0.91 (0.12)	0.90 (0.12)

Note: Standard deviations are reported in parentheses. Sing refers to the Single Task mode conditions; Dual refers to the Dual Task mode conditions; F refers to Fearful expressions; H refers to Happy expressions; N refers to Neutral expressions; and B refers to Blank expressions.

Table 3. Mean amplitudes by ERP component, Group, Task, Expression and Lag.

	Sing Lag2 F	Sing Lag2 H	Sing Lag2 N	Sing Lag6 F	Sing Lag6 H	Sing Lag6 N	Dual Lag2 F	Dual Lag2 H	Dual Lag2 N	Dual Lag6 F	Dual Lag6 H	Dual Lag6 N
Low anxiety												
P100	0.40 (1.50)	0.64 (1.43)	0.46 (1.58)	0.24 (1.11)	-0.16 (0.93)	0.18 (1.21)	0.65 (1.40)	0.58 (1.40)	0.59 (1.41)	0.25 (1.31)	0.26 (1.43)	0.48 (1.08)
N100	0.67 (2.04)	0.89 (2.25)	0.66 (2.07)	-0.59 (1.11)	-0.49 (1.30)	-0.19 (0.93)	1.00 (2.26)	1.01 (2.00)	1.05 (2.09)	-0.28 (1.63)	-0.09 (1.42)	-0.75 (1.54)
VPP	4.15 (2.40)	4.87 (3.42)	4.40 (2.65)	1.13 (2.33)	1.28 (2.43)	0.94 (2.27)	3.27 (2.38)	3.84 (2.60)	3.19 (2.16)	0.92 (2.51)	1.32 (2.12)	0.43 (1.71)
N170 Left	-0.91 (1.61)	-0.81 (1.76)	-0.86 (1.28)	0.21 (1.09)	0.08 (1.14)	0.10 (0.90)	-0.77 (1.84)	-0.75 (1.96)	-0.16 (1.87)	0.39 (1.14)	0.39 (1.03)	0.59 (1.04)
N170 Right	-1.78 (2.05)	-1.70 (1.99)	-1.36 (1.94)	-0.20 (1.65)	-0.41 (1.40)	0.02 (1.54)	-1.40 (1.74)	-1.55 (1.71)	-1.41 (1.74)	0.05 (1.36)	-0.04 (1.30)	0.11 (1.26)
N300 Left	2.46 (2.04)	2.70 (2.48)	2.56 (2.21)	-0.67 (1.88)	-1.03 (2.01)	-0.79 (2.04)	2.26 (2.13)	2.59 (1.97)	2.45 (1.89)	-0.25 (2.08)	-0.56 (1.72)	-0.74 (1.86)
N300 Right	2.23 (2.32)	2.45 (2.46)	2.38 (2.53)	-0.67 (2.12)	-0.73 (1.99)	-0.85 (2.62)	2.58 (2.79)	2.43 (2.60)	2.44 (2.31)	-0.25 (2.46)	-0.76 (2.03)	-0.63 (2.00)
P300	4.10 (3.35)	4.60 (3.88)	4.37 (2.94)	0.80 (3.53)	0.41 (3.35)	0.61 (3.10)	4.24 (3.27)	4.26 (3.51)	4.50 (2.98)	0.15 (2.81)	0.13 (2.43)	0.01 (2.07)
High Anxiety												
P100	0.03 (1.39)	0.02 (1.35)	0.43 (1.69)	0.45 (1.83)	0.52 (1.49)	0.79 (1.09)	0.22 (1.39)	0.53 (1.59)	-0.04 (1.42)	0.91 (1.59)	0.35 (1.15)	0.86 (1.38)
N100	0.71 (1.37)	0.51 (2.02)	0.69 (1.76)	-0.43 (1.21)	-0.43 (1.08)	-0.51 (1.12)	0.14 (1.90)	0.74 (1.89)	0.93 (1.58)	-0.46 (1.04)	-0.31 (1.59)	-0.29 (1.25)

VPP	3.97 (2.57)	4.47 (3.07)	3.66 (2.50)	0.27 (1.93)	1.56 (2.06)	0.49 (2.22)	2.16 (2.81)	3.29 (2.39)	2.84 (2.80)	0.35 (1.78)	1.32 (2.69)	0.36 (1.95)
N170 Left	-0.26 (1.52)	-0.47 (1.51)	-0.26 (1.16)	0.36 (1.30)	0.50 (1.25)	-0.02 (1.30)	-0.38 (1.44)	-0.57 (1.08)	0.05 (1.24)	0.38 (1.18)	0.39 (0.92)	0.53 (0.90)
N170 Right	-1.83 (1.93)	-2.57 (1.79)	-2.12 (1.92)	-0.02 (1.50)	-0.51 (1.41)	-0.12 (1.55)	-1.51 (1.95)	-1.87 (2.05)	-1.47 (1.62)	0.27 (1.37)	-0.24 (1.39)	0.18 (1.34)
N300 Left	3.09 (2.32)	2.96 (2.82)	2.82 (2.77)	-0.12 (2.08)	0.08 (2.03)	-0.68 (2.79)	2.06 (2.53)	2.56 (2.24)	2.26 (2.90)	-0.22 (2.22)	-0.33 (2.80)	-0.69 (2.18)
N300 Right	3.08 (2.23)	2.67 (2.83)	2.68 (1.94)	-0.48 (2.01)	-0.30 (2.46)	-0.80 (2.39)	2.15 (2.50)	2.52 (2.14)	2.63 (2.06)	-0.70 (2.19)	-0.40 (2.77)	-0.71 (2.06)
P300	4.27 (2.30)	3.91 (2.30)	3.74 (1.69)	0.08 (1.53)	0.34 (1.74)	0.32 (2.17)	3.35 (3.07)	3.77 (2.46)	3.63 (2.61)	0.10 (2.26)	0.51 (2.71)	0.48 (2.57)

Note: Standard deviations are reported in parentheses. Sing refers to the Single Task mode conditions; Dual refers to the Dual Task mode conditions; F refers to Fearful expressions; H refers to Happy expressions; N refers to Neutral expressions; and B refers to Blank expressions.

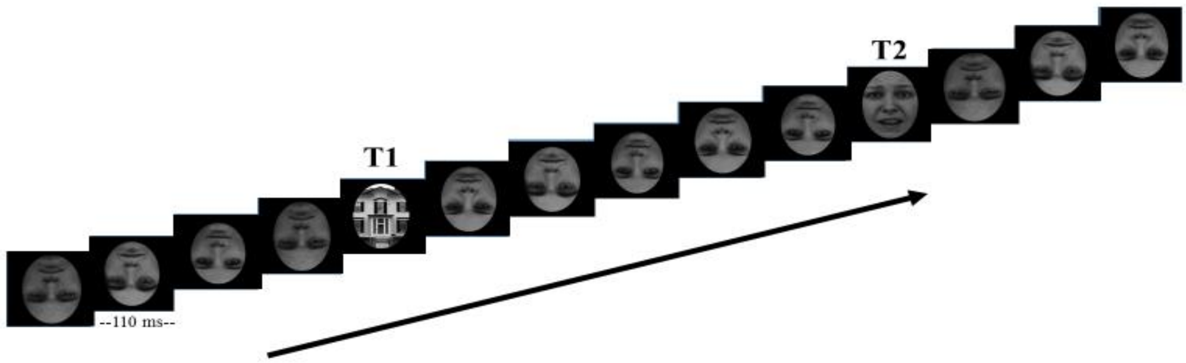
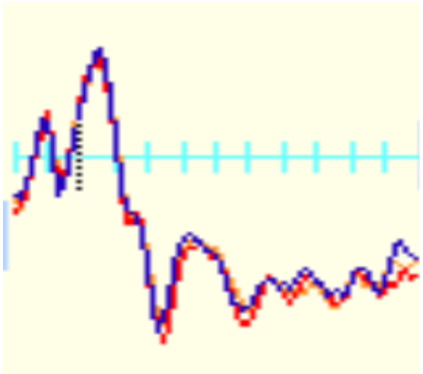
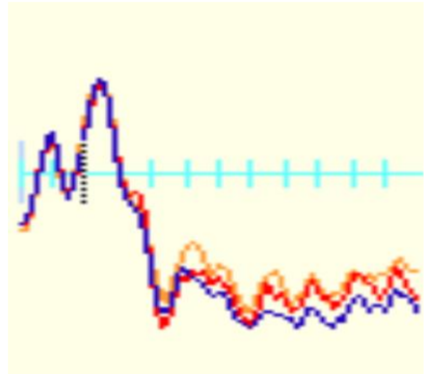


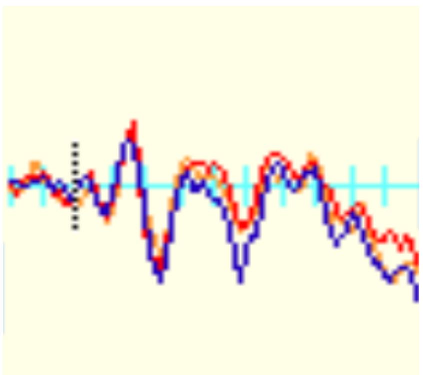
Figure 1. Overview of trial presentation from Luo et al. (2010) which the current study replicated *Note*: T1 refers to the first target image; T2 refers to the second target image. In this example, the first target (i.e. the house) is in the 5th position of the series, and the second target (i.e. the fearful face) appears in the 6th position following the first target (i.e. Lag6).



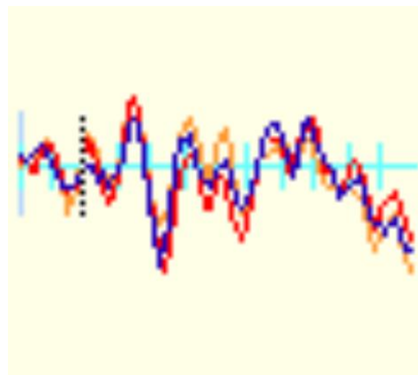
a) Low Anxiety Single Task Lag 2



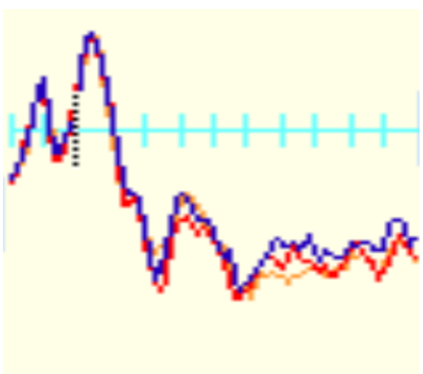
b) High Anxiety Single Task Lag 2



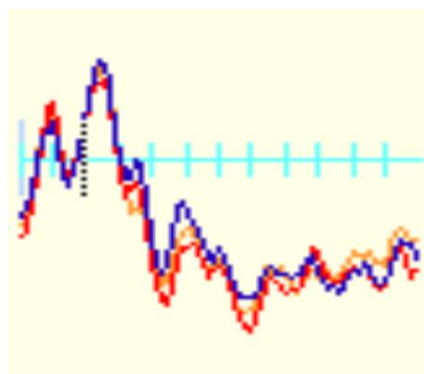
c) Low Anxiety Single Task Lag 6



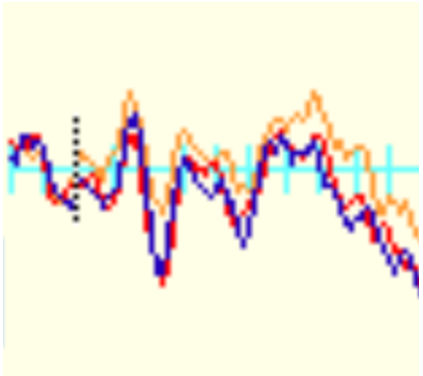
d) High Anxiety Single Task Lag 6



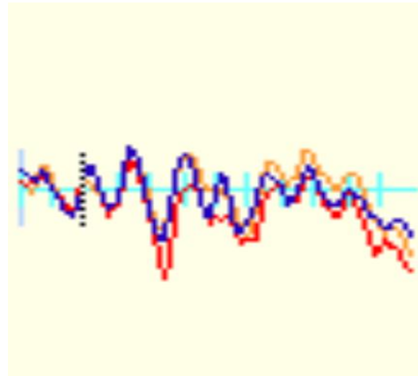
e) Low Anxiety Dual Task Lag 2



f) High Anxiety Dual Task Lag 2



g) Low Anxiety Dual Task Lag 6



h) High Anxiety Dual Task Lag 6

Figure 2. Waveforms comparisons by emotion for each group and condition, starting from 200 milliseconds pre-stimulus onset and continuing until 900 milliseconds post-stimulus onset. *Note:* Stimulus onset is represented by a dotted vertical line. All presented waveforms are from electrode 4 (between Fz and Cz). Waveforms for fearful expressions are presented in blue; waveforms for happy expressions are presented in red; waveforms for neutral expressions are presented in orange.