DIFFERENTIAL LATERALIZATION OF TRAIT ANXIETY AND TRAIT FEARFULNESS: EVOKED POTENTIAL CORRELATES

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Spencer, K. M., Dien, J., and Donchin, E. (1999). A Componential Analysis of the ERP Elicited by Novel Events Using a Dense Electrode Array. Psychophysiology, 36:409-414. (https://doi.org/10.1016/S0191-8869(98)00144-5)

Abstract

There is an ongoing debate on whether the terms anxiety and fear denote distinct states. Brain imaging studies suggest they may indeed be dissociable and are differentially lateralized. A study of 54 normal college students successfully found doubly dissociable electrophysiological correlates of trait anxiety and fearfulness that had the predicted laterality. Trait anxious participants displayed a left-lateralized visual N1 (localized to the temporo-parietal junction) whereas trait fearful participants presented a right-lateralized P1r (localized to the superior parietal region). These findings support the proposal that trait anxiety and trait fearfulness are distinct personality dimensions with distinctive patterns of laterality.

Key-Words: anxiety, event-related potentials, laterality, N1, P300, emotions

Author's Note

This research was supported in part by NIMH grants MH42129, MH42669, MH18935, MH19554, and MH11751, by a grant from the Pew Memorial Trusts and the James S. McDonnell Foundation to support the Center for the Cognitive Neuroscience of Attention, and by Small Business Innovation Research grant MH51069 to Electrical Geodesics Incorporated, Eugene, Oregon. Thanks to my dissertation committee (Mike Posner, Libby Schaughency, Don Tucker, and Rick Zinbarg) for their advice in carrying out this study. Thanks also to Greg Miller and Keo Tatiano for their helpful comments on an earlier draft.

This paper is based on a doctoral dissertation submitted to the University of Oregon in 1995. Portions of these findings were presented at the meeting of the American Electroencephalography Society (Washington DC, 1995) and at the meeting of the Society for Psychophysiological Research (Toronto, 1995).

The Question of Anxiety and Fear

Trait anxiety is an individual difference variable that has attracted particular experimental interest. Studies have found a wide array of behavioral differences in the high trait anxious, including narrowed attention, heightened automatic responses, and bias towards threatening stimuli. For clinicians, it throws light on neurotic disorders. For personality psychologists, it is related to two of the major self-report personality dimensions (neuroticism and introversion). For emotion researchers, it is the chronic expression of one of the better studied emotions.

For all this interest, trait anxiety remains poorly understood. One problem plaguing researchers has been multiplying constructs with uncertain interrelationships (e.g., anxiety, fear, worry, emotionality, arousal, etc.). A related issue is that these instruments are typically all moderately intercorrelated, leaving issues of discriminant and convergent validity clouded.

Two common measures that particularly call for examination are the Speilberger State-Trait Anxiety Inventory (STAI) and the Fear Survey Schedule (FSS). The STAI (Speilberger, 1983) is the most commonly used instrument for measuring anxiety in experiments. Experimenters have found it particularly attractive because it yields scores for both state anxiety and trait anxiety. The latter section asks raters the self-descriptiveness of such phrases as “I lack self-confidence”.

The FSS (Wolpe & Lang, 1964) was developed in the context of behavioral therapy of fear disorders, particularly phobias. It assesses how much the rater fears a wide variety of stimuli compiled from clinical experience (e.g., suffocating, angry people, blood). Several versions have been developed with differing numbers of items but are largely similar.

Studies typically rely on just one or the other measure, depending on which has been customary for that line of inquiry. While these two measures are clearly related, it is unclear in what manner. It could be argued that they both measure the same construct; the two typically correlate in the range of about .27 to .60 (Hersen, 1973). Measurement specific variance (due to the different question formats) could be responsible for the divergence between the two measures.

Alternatively, they could measure distinct constructs. Some clinicians (Barlow, 1988; Öhman, 1993) have argued that neurotic pathologies fall into two distinct groups, those of anxiety (e.g., generalized anxiety disorder, obsessive-compulsive disorder) and of fear (e.g., phobia, post-traumatic stress disorder, panic disorder). Barlow describes anxiety as a system of associated thoughts, memories, and autonomic responses whereas fear is a primitive emergency response. Öhman makes a similar argument, making the additional proposal that fear is set off by preconscious feature detectors whereas anxiety can be set off by either preconscious significance evaluators or postconscious expectancy systems. It is therefore possible that the FSS and the STAI may measure the trait expression or susceptibility to these two states. The moderate correlation could arise from co-occurence or common measurement error (like acquiescence bias). It is not yet clear from these theories how this putative dichotomy could be tested.

Inspired by clinical observations, some behavioral neuroscience researchers have proposed biological systems that could underlie these two states. An influential formulation (Gray, 1982; Gray & McNaughton, 1996) suggests that the septo-hippocampal system acts as a comparator, detecting unexpected events. In such cases a behavioral inhibition system (BIS) is activated which halts current motor programs, increases arousal, and triggers orienting to the unexpected event. Anxiety would represent chronic activation of this system. Panic (what might also be called fear) is suggested to be the activation of a fight/flight system centered on the central gray and triggered by the amygdala (Gray, 1987). While the anxiety system is well defined, the eliciting conditions and behavioral concomitants of the fear system remains rather vague and so it would be difficult to empirically distinguish them, particularly since both are proposed to produce physiological arousal.

The most promising proposal of anxiety and fear that lends itself to experimental tests is that anxiety (anxious anticipation) may be left-lateralized and fear (anxious arousal) right-lateralized (Heller, Etienne & Miller, 1995). Many cerebral blood flow studies have found that anxiety disorders involve greater left frontal regions (Baxter et al., 1987; Breiter et al., 1996; Johanson, Smith, Risberg, Silfverskiold & Tucker, 1992; Johanson, Risberg, Silfverskiold & Smith, 1986; Rubin, Villanueva-Meyer, Ananth, Trajmar & Mena, 1992; Swedo et al., 1989), although one report found left anterior orbital but right orbital lateralization (Nordahl et al., 1989). This generalization has to be limited by the repeated finding that treatment improvements are correlated most with right hemisphere deactivation (Baxter et al., 1992; Buchsbaum et al., 1987; Swedo et al., 1992), resulting in suggestions that obsessive-compulsive disorder (OCD) at least is more related to right hemisphere mechanisms. In view of the other studies, it seems more plausible that the left hemisphere is more involved in the anxiety process and the right hemisphere is more involved in the immediate recovery process.

Fear disorders (phobic responses and panic), on the other hand, generally involve right hemisphere activity (O'Carroll et al., 1993; Reiman, Raichle, Butler, Herscovitch & Robins, 1984; Stewart, Devous, Rush, Lane & Bonte, 1988), although bilateral activation has also been reported (Fredrikson et al., 1993). Additionally, OCD patients reporting feelings of panic during the recording session showed greater right prefrontal activation (Swedo et al., 1989), although this activation also correlated with state anxiety scores, as measured by the State-Trait Anxiety Inventory (Speilberger, 1983). None of these reports involve the temporal pole regions that were reported activated in response to lactate-induced panic attack (Reiman, Fusselman, Fox & Raichle, 1989a) and shock threat (Reiman et al., 1989b) and were later attributed to jaw muscle artifact (Drevets, Videen, MacLeod, Haller & Raichle, 1992). Finally, of 15 epileptic patients who experienced ictal fear (the sudden experience of fear without apparent cause, thought to be due to the abnormal burst of activity from the epileptic foci), 13 were found to have seizures originating in the right temporal lobe (Hermann, Wyler, Blumer & Richey, 1992).

There is also some supporting behavioral evidence for lateralization. OCD patients have been repeatedly found to have impaired at right hemisphere visuo-spatial tasks while being normal or better at verbal tasks (Aronowitz et al., 1994; Boone, Ananth, Philpott, Kaur & Djenderedjian, 1991; Zielinski, Taylor & Juzwin, 1991). It is unclear whether other putative anxiety disorders also display such signs of lateralized bias.

Another possible link between fear and the right hemisphere is the finding that arousal produces a tunnelvision effect, focusing attention and causing peripheral cues to be neglected (Easterbrook, 1959). This effect is said to affect both spatial attention, slowing responses to peripheral locations, and problem-solving, causing secondary information to be ignored. More recent work concerning spatial attention has suggested that arousal focuses attention on the most relevant locations, only directing attention to the center when it is confounded with relevance (Cornsweet, 1969; Geen, 1980). One difficulty with this formulation is that it predicts that anxiety (as a source of arousal) should promote improved task focus (Eysenck, 1982). Evidence suggests rather that anxiety may cause increased distractibility (Deffenbacher, 1978) and lowered processing efficiency (Eysenck & Eysenck, 1985). These studies have not sought to make any distinction between anxiety and fear so it is quite possible that this effect is more characteristic of fear, accounting for this contradiction.

There is reason to think that the Easterbrook effect may reflect right-lateralized processes and fear in particular. Experiments with animal models suggest that the norepinephrine (NE) arousal system mediates narrowing attention to relevant cues (Minor, Jackson & Maier, 1984; Selden, Cole, Everitt & Robbins, 1990), much as the Easterbrook effect is said to do. There is some evidence that this arousal system is in turn right-lateralized (Tucker & Williamson, 1984). For example, lesions of the frontal pole of the right hemisphere, but not the left hemisphere, can produce depletion of cortical NE (since the NE tract curves over the front of the cortex, lesions at this point can block the supply to the entire neocortex) (Pearlson & Robinson, 1981). NE has been implicated in the alerting functions of the right parietal (Posner & Petersen, 1990), an area that has also been implicated in visual selective attention (Corbetta, Miezin, Shulman & Petersen, 1993). Finally, NE has been particularly implicated in fear disorders. NE is abnormally high (Butler, O'Halloran & Leonard, 1992) and abnormally regulated (Charney & Heninger, 1986) in panic patients. It has also been demonstrated that there is an extensive connection between somatic defense reactions (as found in panic attacks) and tonic activity in the locus coeruleus, which originates the bulk of the NE system (Svensson, 1987).

It is not proposed that anxiety and fear involve global lateralized activity but only some functions within each hemisphere. Indeed, a substantial case has been built with EEG studies that the prefrontal regions show a different pattern of lateralization of affect with positive mood correlating with left hemisphere activation and negative mood with right hemisphere activation (Davidson, 1984; Fox, 1991; Wheeler, Davidson & Tomarken, 1993), although a case has been made for the opposite as well (Tucker & Williamson, 1984). These findings have been shown for both state and trait differences. A more recent study with PET has shown a complementary picture (Dolski et al., 1996). On the other hand, such EEG measures have yielded mixed results for anxiety with one study reporting left frontal activity for worriers (Carter, Johnson & Borkovec, 1986) while another reported no such lateralization for trait anxiety (Tomarken & Davidson, 1994).

It should be emphasized that this account is not meant to be a reductionistic one, that anxiety and fear are defined solely by the activation of these systems. Psychopathologies in particular are the result of complex interactions of many levels and so the primary question is whether there are natural dividing lines, especially at the neural systems level where brain imaging methods can be informative.

Choosing the Task

A critical question is the nature of the experimental task. While it would be ideal to induce the desired state and control it experimentally, it is uncertain what inductions might produce these two emotions. For example, a threat of electrical shock might very well produce either or both states. There are also ethical issues in inducing anxiety and fear states in participants. It therefore seems reasonable to seek these effects in trait anxious and fearful participants. Moreover, psychometric instruments are the most overtly designed to distinguish between these two states. The reasoning is that trait anxious and fearful participants will be the most likely to also be experiencing the state at any given time (Speilberger, 1985). In addition, as social psychologists have demonstrated, experiments are inherently motivated situations in terms of evaluation concerns, novel experiences, and desire for the enterprise to succeed (Orne, 1969; Rosenthal, 1969). Thus, even a nominally unemotional task can sustain emotional states, albeit at a modest level consistent with normal activities.

Current anxiety research focuses on responses to emotional stimuli such as words, pictures, or conditioned sounds. The difficulty with using such a paradigm for distinguishing anxiety and fear is that it cannot be determined at this point what stimuli might elicit anxiety and what might elicit fear. An experiment with stimuli that are primarily anxiety producing is likely to mask any fear-related effects. Instead, it seems best to avoid these complications by relying, at least at first, on non-emotional stimuli. Much of the older anxiety literature was conducted with such stimuli and found reportable effects. The visual attention effects reviewed by Easterbrook were found with simple visual probes (Easterbrook, 1959). Although there is a tendency to separate affect and cognition into independent domains, this is a false dichotomy.

For the task itself, a reasonable one might be between object recognition and spatial processing. The OCD studies cited earlier suggest that anxious subjects might be impaired at right hemisphere visuospatial tasks while Heller's model suggests that fearful subjects might be better due to their parietal activation. Whereas spatial processing is mediated by a dorsal pathway that includes the parietal, object recognition mostly follows a separate ventral pathway (Ungerleider & Mishkin, 1982). It therefore provides a logical task to contrast with spatial judgment. While object recognition can involve both left and right lateralized processes (Kosslyn, 1994), judgments about the identity of digits might be expected to be left-lateralized since reading in general is left-lateralized.

The object versus spatial distinction has been examined in a number of ERP studies and laterality effects have already been found (Harter & Aine, 1984). The usual spatial task of judging location is likely to cause participants to attend to the target location; interpretation would be complicated by the possible presence of both effects in the right hemisphere spatial processing circuits (due to increased processing of spatial information) as well as in the left hemisphere object recognition circuits (due to attentional gating of object information at the target location). For this reason, the spatial task chosen was that of motion judgment, a task that is known to be right-lateralized (Vaina, 1989; Zeki et al., 1991) and has been reported to produce a right hemisphere ERP feature (Neville & Lawson, 1987).

Effects are expected in the early negativities and the P3 components. While anxiety has been reported to affect the early negativities (Beech, Ciesielski & Gordon, 1983; Shagass, 1983), it is unclear which ones. The N1 and the categorical N2 topographies, for example, overlap quite extensively even in high-density recordings (Dien & Tucker, 1995). Without such topographical information it is quite difficult to distinguish between an enhanced N1 (Shagass, 1983) and an earlier categorical N2 (Beech et al., 1983; Ciesielski, Beech & Gordon, 1981). There are reports that neurotics and obsessives can display faster and smaller P300s (Beech et al., 1983; Stelmack, Houlihan & McGarry-Roberts, 1993), suggesting they are evaluating the stimuli faster (c.f., Kutas, McCarthy & Donchin, 1977). No ERP studies have explicitly contrasted anxiety and fear so it is unclear what to expect.

In general, it is predicted that trait anxious participants will display evidence of left-lateralized activity in their evoked potentials and a relative superiority of object recognition. Trait fearful participants are expected to display evidence of right-lateralized activity and a relative superiority of spatial judgment. It is also expected that trait fearful participants will show evidence of the Easterbrook effect by showing better performance for centrally presented stimuli relative to peripheral stimuli (the central positions are the most relevant to the subject since they can both be monitored simultaneously whereas the peripheral positions cannot, making in effect a 25/50/25 probability situation).

Methods

Participants

Sixty-three right-handed University of Oregon undergraduates were recruited from psychology classes. The participants were required to be fluent English readers with normal or corrected to normal vision and to not wear contact lenses (to reduce blink artifact from dry eyes). Two participants declined when the experimental procedure was described. Five participants were lost due to equipment failure. One participant was dropped due to poor English. Two participants were dropped due to the loss of their questionnaire data. One participant was dropped due to excessive artifact and incorrect answers during the behavioral task, leaving 54 participants (22 males and 32 females; mean age 20).

Apparatus

Electroencephalographic (EEG) data were collected from 64 recording sites, plus a right mastoid reference sensor, with the Geodesic Sensor Net (Tucker, 1993). The Geodesic Sensor Net consists of a geometric (tessellated icosohedron) tension structure stabilizing a dense array of plastic tubes holding sponge Ag/AgCl sensors. The Net allows rapid, comfortable applications, requiring 15-20 minutes including impedance testing (10 to 40k ohms) for 64 channels. After amplification with a 0.15 Hz to 50 Hz (3 dB attenuation) bandpass and a 60 Hz notch filter, the signals were digitized with a 16-bit A/D converter at a rate of 250 samples/sec using a National Instruments NB-MIO16 16-bit analog to digital board. A Macintosh II computer collected the digitized data as well as handling stimulus display using EGIS (Electrophysiological Graphical Interface System).

Procedure

In each block participants judged whether the moving number stimuli were either odd/even or moving upwards/downwards. There were six blocks of 80 trials. In half the blocks the participant judged even/odd and in the other half (alternating) the judgment was up/down; the stimuli were the same in both tasks. Which task went first was counterbalanced across participants. Responses were made by depressing one of two microswitches with the appropriate index finger (counterbalanced). Participants were instructed to blink as little as possible and to blink after number presentation when necessary (blinks prior to the recording epoch can have undetected carryover effects). The first trial of each block has been discarded as atypical. The intertrial period was a constant 1700 msec.

Participants were seated 40 cm from the computer screen with a chin rest to minimize movement. On the screen, a central fixation point ('•') is present throughout the block. Each trial consists of 184 msec. prestimulus baseline recording followed by the presentation of a moving number. These stimuli consisted of the digits 2 through 9 drawn in white 48 point Geneva font on a black screen (1.4 degrees visual angle wide). Apparent motion was produced by displaying the digit for 33 msec. at the first location, then shifting it five times (each for 33 msec.) for a total of 198 msec. Presentation time was kept below 200 msec. to minimize saccades. To make trajectories as varied as the visual forms, stimuli moved at eight each upward and downward trajectories (four each leftward and rightward: 45˚ from horizontal/.1˚ per shift; 63˚/.1˚; 63˚/.2˚; 76˚/.2˚). Stimuli appeared at one of four locations: left and right periphery (at 15 degrees visual angle) and at left and right central (at one degree visual angle). Since the constant presence of the fixation point facilitates judgment of up/down for central locations, '•'s were also maintained on the outside periphery. Match/mismatch with the category membership of the previous trial by number and by direction of motion was controlled to be of equal probability. The recording epoch lasted for 1667 msec. after stimulus offset. Participants were asked to respond as quickly as possible while still being accurate.

Psychometrics

A number of different psychometric measures were administered as well. During the midpoint break, participants completed the PANAS mood inventory (Watson, Clark & Tellegen, 1988). This instrument is designed to provide a quick and simple measure of positive and negative affect and was included to distinguish between anxiety/fear effects and the more general mood effects described by Davidson and colleagues. After completing the experimental task, participants had the recording equipment removed and were led into another room where a Macintosh computer presented them with a series of questionnaires via a Hypercard program. Participants were allowed to choose "no answer" in which case the item was scored as a missing item and estimated as the mean of the intact scores. These questionnaires were given in the following order:

<u>Speilberger State-Trait Anxiety Inventory (STAI)</u> (Speilberger, 1983) - is the most commonly used experimental measure of state and trait anxiety. This instrument assesses a number of cognitive, behavioral, and affective symptoms of anxiety.

<u>Marlowe-Crowne Social Desirability Inventory (MC)</u> (Crowne & Marlowe, 1964) - might be used to help control for repression (Weinberger, Schwartz & Davidson, 1979). This instrument assesses the participant's tendency to deny negative characteristics, a tendency that could possibly interfere with accurate assessment of mood and character.

<u>Fear Survey Schedule (FSS)</u> (Braun & Reynolds, 1969) - is the most commonly used experimental measure of trait fearfulness. This version of the instrument (Temple Fear Survey Inventory, TSFI) assesses fear of 100 common phobic stimuli

A number of other instruments were given only to some of the later participants on an exploratory basis or were not completed by all the participants and will therefore not be reported.

Data Analysis

Participant averages were computed using an automatic editing program. Trials containing blinks (criteria of 30 μv difference between vertical EOG channels) were discarded. A given channel's recording was considered bad if it either changed by more than 50 μv between samples or exceeded +/-100 μv in any case. Trials were discarded if

10 or more channels were deemed bad by these criteria. For trials with less than 10 bad channels, only the bad channels were discarded while the good channels were included in the average. Trials with incorrect responses were also excluded. The resulting recordings were digitally filtered with a 30 hz lowpass filter to reduce high frequency noise. Waveforms were baseline corrected using the 184 msec. prior to stimulus onset. Waveforms were given an average reference transformation to minimize artifact due to reference site activity (Bertrand, Perrin & Pernier, 1985; Dien, 1998).

Results

Psychometrics

The results suggest the participants constitute a representative sampling across the domains measured by the surveys. For the STAI, for which comprehensive norms are available, trait scores were only slightly above the published norm of 38.30 for men and 40.40 for women (40.5 and 42.8 respectively). These scores also indicate a wide range of scores extending from the 14th to the 99th percentiles. STAI-state norms are not relevant since state scores by their nature will be dependent on the testing situation. Norms are not available for this version of the FSS. Comparable to previous results, the correlation between the FSS and the STAI-trait was .40.

The accuracy and reaction time of the participants were examined first. Mean reaction times are calculated over correct trials only. Mean accuracy is calculated as accurate trials versus errors and time-outs. Greenhouse-Geisser epsilons are used for all analyses. Only corrected p-values and unmodified degrees of freedom are reported. ANOVAs were carried out with within-participant factors of task (object, motion), field of vision (left, right), and location (central, peripheral). Although from the grand linear model perspective it should be possible to combine the continuous psychometric variables and the categorical condition variables using an ANCOVA, there do not appear to be any readily interpretable methods for conducting the follow-up post-hocs and graphs to interpret interactions involving the two psychometric variables. Some potential statistical power will therefore be sacrificed in the interests of interpretability by trichotomizing <u>trait anxiety</u> and <u>trait fearfulness</u> (low, medium, and high 3rds) as between-participant factors. Unfortunately, in order to maximize the number of correct trials available for the ERP averages, the accuracy rate was set to be quite high, limiting the utility of the behavioral measures.

The correlation between the STAI-trait and FSS scores causes problems for the ANOVA procedure since it requires orthogonality. It is possible to address this issue by partialling out the shared variance from one of the variables, in effect allocating the shared variance to the other variable (partialling out both variables would reintroduce their correlation, but reversed in sign). This partialling procedure is equivalent to using a hierarchical regression procedure. There are three primary scenarios for what effect this course of action would have. 1) Both instruments may measure the same construct with their correlation reduced by differences in rating format or low reliabilities. In this case, this procedure should reduce or eliminate significant effects from the corrected variable. 2) The measures may measure different constructs that happen to be correlated. In this case, partialling should reduce significant effects to the extent that the two constructs are correlated. 3) The measures may share variance unrelated to the construct or constructs responsible for effects of interest. In this case, partialling should improve the significance level of effects for the corrected variable as noise variance will have been removed.

Analyses were conducted with both FSS partialled from STAI-trait and vice versa. The former produced no significant group effects except for a complicated trait anxiety by fearfulness reaction time interaction that suggested the two measures were still confounded (F [4, 45] = 2.88, mean squared error [mse] = 92372, p = .033). The latter partialling procedure (beta = 3.53, intercept = 129.45) yielded results in accordance with expectations and will therefore be used for the remainder of this paper. Making this choice is equivalent to utilizing a stepwise regression procedure which partials out the variable resulting in the most significance. Although the choice is relatively arbitrary, it is anchored by the theoretical expectations described in the introduction. Further studies will be required of course to verify and extend this conclusion as for any study covering new ground. See Table 1 for the mean scores of the resulting groups. This residualization caused the reclassification of some of the subjects: 4 of 18 high FSS subjects became medium FSS, 3 of 18 low FSS subjects became medium FSS, 4 of 18 medium FSS became high FSS, and 3 medium FSS became low FSS.

Insert Table 1 about here

As predicted, high trait anxiety produced faster object processing than motion processing (task * trait anxiety, F [2, 45] = 3.29, mse = 15002, p = .046), although the separation is clearest for medium anxiety. As seen with OCD patients, the significant interaction was due to impairment of spatial processing (Figure 1); when broken down by task, there is no main effect for object judgments whereas there is for motion judgments (trait anxiety, F [2, 51] = 3.32, mse = 196239, p = .044). High trait anxiety also caused motion judgments to be less accurate (Figure 2), particularly for stimuli in the left visual field (task * field * trait anxiety, F [2, 45] = 3.23, mse = .002, p = .049). These interactions could be due to ceiling effects though. A simple main effect could produce an interaction if one of the conditions was already at ceiling.

Insert Figures 1 and 2 about here

Trait fearfulness produced an Easterbrook effect as expected from the norepinephrine literature (location * trait fearfulness, F [2, 45] = 3.40, mse = 3281, p = .042). Both medium and high fearfulness participants were slower to peripheral stimuli than low fearfulness participants (Figure 3). Ceiling effects are again an issue.

Insert Figure 3 about here

There was also a complex four-way reaction time interaction (trait anxiety * trait fearfulness * field * task, F [4, 45] = 2.72, mse = 1576, p = .042). Decomposing this interaction is problematical since the group counts drop quite low. Low anxious participants are faster when highly fearful especially for central stimuli (trait fearfulness * location, F [2, 15] = 4.349, mse = 1276, p = .032), even though location did not appear in the original interaction. The medium anxious are faster for motion stimuli (task, F [1, 15] = 5.753, mse = 13273, p = .030) and faster for right stimuli in the center and slower for those in the periphery (field * location, F [1, 15] = 6.128, mse = 1022, p = .026). Nothing reached significance for high anxious participants, although a task by field by trait fearfulness interaction just missed significance (F [2, 15] = 3.679, mse = 634, p > .05).

Insert Figure 4 about here

The state anxiety measure did not yield any reaction time effects and only a single significant accuracy interaction (state anxiety * field, F [2, 51] = 7.27, mse = .001, p = .0017, e = 1.0). This effect consisted of an unclear pattern by which low state anxious were more accurate for left field stimuli (F [1, 17] = 5.02, p = .039), medium state anxious were more accurate for right (F [1, 17] = 10.12, p = .0055), and high state anxious were equally accurate for both fields (F [1, 17] = .683, p = .42). Although trait anxiety effects are usually considered to be mediated by state anxiety, the state anxiety measure was taken after the experimental session and may not accurately reflect anxiety during the session itself.

The PANAS (negative) measure was taken during the session itself but did not yield any significant effects. The Marlowe-Crowne measure did not produce any notable improvements when partialled out from the STAI-trait and the FSS measures.

Although the behavioral measures provide some grounds for support of the laterality hypotheses, physiological measures are necessary for more direct evidence.

Grand Average Waveforms

Grand averages were generated by averaging together the participant averages. Plots are shown comparing the central vs. peripheral stimuli (Figure 5). As can be seen, evoked potentials to the peripheral stimuli are less clearly defined and hence less likely to provide useful results.

Insert Figure 5 about here

Principal Components Analysis

The primary goal of the evoked potential analyses is to detect lateralized asymmetries related to the emotionality differences. The complexity of a high-density ERP dataset makes it difficult to apply conventional analysis procedures. If a paper fully analyzes a given dataset, it will be rightfully criticized for having an unacceptable Type I error rate due to an inordinate number of tests. If a paper analyzes only selected features, this same paper may be criticized for ignoring potentially interesting features. Often the same paper will have both types of criticisms leveled at it by different reviewers. The present report will choose the lesser of two evils, focusing on the a priori topic of interest (laterality effects).

Even so, comparing pairwise all the lateral pairs (29) of electrodes for each of the visible features would still require an enormous number of comparisons; the necessary post-hoc correction factors would reduce statistical power to an unacceptable degree. The electrodes could be grouped into regional averages (c.f., Curran, Tucker, Kutas & Posner, 1993) but such a procedure would reduce statistical power by mixing together active and inactive sites.

A promising approach is to use principal components analysis (PCA) to summarize the latent basis waves of the dataset (Curry et al., 1983; Donchin & Heffley, 1979; Möcks & Verleger, 1991). A simple test for laterality effects can then consist of identifying for each factor the electrode with the largest absolute mean factor score (the site where the factor is largest when averaged across all the subjects and conditions) and comparing it with the homologous site on the other side of the head. The simplifying assumption behind this operation is that the factor mostly represents a single component, which is not unreasonable given that the topographies are coherent and (as will be seen later) readily modelled as due to a single source. In such a case, due to volume conduction of the electrical fields, each site should largely reflect the same activity. The site with the largest mean amplitude is chosen as most representative since it is expected to have the largest signal to noise ratio. Although one it is a legitimate concern that some localized effect (due to a confounded ERP component) might be missed in this manner, testing for experimental effects at all electrode sites, separately for each factor, would require 520 tests which would incur unacceptable Type I error rates and defeat the goal of data reduction. Using an index site for each factor allows us to restrict the analysis to just the strongest influences in the data, just as psychometricians routinely utilize aggregated scales for dependent variables rather than the less reliable item level variables.

Midline electrodes could not be used so the largest non-midline site would be used. Likewise, the channels surrounding the eyes should not be used as they are particularly likely to have eye artifacts that could produce artifactual asymmetries. Although PCA can suffer from misallocation of variance (Wood & McCarthy, 1984), such a problem is not expected to produce spurious asymmetries. In this regard, the only concern is that misallocation can cause a legitimate asymmetry to be spread over multiple factors so only if several factors have the same pattern would this be an issue.

A temporal PCA was carried out on the first half of the recorded epoch (the first 256 samples, comprising 1024 msec.). The observations consisted of the waveforms from all 65 average referenced channels from the 54 participants in the eight different conditions. The resulting scree chart indicated the retention of eleven factors accounting for 93% of the variance (Figure 6). These factors were then rotated to simple structure using Promax (Hendrickson & White, 1964), an oblique rotation that allows factors to be correlated (Dien, 1997). The factors reflect the P1, N1, N2c, P1r (Tucker, Liotti, Potts, Russell & Posner, 1994), P300, Slow Wave, and the O-wave. Four factors were of negligible size, irregular, and not readily interpretable.

Insert Figure 6 about here

Three significant laterality effects were found for central stimuli (Figures 7 and 8). The P300 factor peaked at 424 msec. and had index sites in between Cz and C3/4. The factor was larger over the right hemisphere for the high trait anxious (r = .29, p = .034). The N1 factor peaked at 172 msec. and had index sites just anterior and inferior to P3/4. The factor was larger over the left hemisphere for the high trait anxious (r = .39, p = .0038). The P1r factor peaked at 292 msec. and had index sites just anterior and superior to P3/4. The factor was larger over the right hemisphere for the high trait fearful (r = .35, p = .0097). No effects were found for peripheral stimuli, perhaps because the evoked potentials were not as clearly defined.

If, as suggested by the behavioral data, partialing the STAI-trait scores from the FSS scores is more useful than the opposite operation, these correlations should be lower for the latter. Indeed, although the latter two correlations are still quite significant they are somewhat smaller. The N1 factor has a smaller but still highly significant correlation with the partialled trait anxiety score (r = .37, p = .0057). Likewise the P1r factor has a smaller but still significant correlation with the unmodified FSS score (r = .29, p = .033). The correlation of the P300 laterality with the partialled trait anxiety score barely misses significance (r = .24, p = .08).

Insert Figures 7 and 8 about here

Dipole localization

Once PCA has been used to simplify the evoked potential data, the generators of the evoked potentials contributing to the factors can be modeled (c.f., Dien, Tucker, Potts & Hartry, 1997). Dipoles were fit to the three factors of interest using Brain Electromagnetic Source Analysis (BESA) version 2.2 (Scherg & Berg, 1996). The factors were modeled as pairs of dipoles with locations and orientations constrained to be symmetric. In order to minimize distorting interactions within the pairs, the energy minimum criteria was set at 20% as advised in the user manual. Since the topography of each factor is uniform across the entire time course, the latency of the dipole fit is irrelevant. A moving dipole fit was conducted in which the locations and orientations of the dipoles were iteratively shifted until an optimal fit is found. Since PCA simplifies the structure of the raw evoked potential, local minima were not expected to be an issue. Nonetheless, the fitting was repeated for several starting positions and identical solutions were found for each.

The P300 factor was not modeled since BESA approximates electrical events using equivalent point dipoles (asking where an evoked potential would be located if its generator was a single point). Such a model is poorly suited for localizing a broadly distributed event like the P300 which appears to have multiple sources (Molnar, 1994).

For the N1 factor, the solution accounted for 95.78% of the variance. Since a broadly distributed generator site will be modeled as a more deeply situated point dipole, the result is compatible with a broad generator site in the temporo-parietal junction region (Figure 9A).

For the P1r factor, the solution accounted for 96.86% of the variance. The equivalent dipole is compatible with a broader generator site located on the upper surface of the superior parietal cortex (Figure 9B).

Insert Figure 9 about here

Discussion

The results of this study support the proposed dissociation between trait anxiety and trait fearfulness. Despite a moderate correlation between the trait anxiety and fearfulness measures, distinct evoked potential effects were associated with the two measures. Moreover, the behavioral measures were compatible with the suggestion that anxiety produces a bias toward recognition and fear produces a narrowing of spatial attention. Unfortunately, the behavioral measures may be due to ceiling effects. More significantly, the two strongest evoked potential correlates fulfill the prediction that trait anxiety is characterized by left hemisphere activation and trait fearfulness by right hemisphere activation.

A number of caveats must be observed. While the scalp lateralization is very suggestive, localization of scalp features is challenging without convergent validity from independent methods. For example, in some cases paradoxical lateralization can be seen when a dipole in one hemisphere points toward the opposite side of the scalp, resulting in an evoked potential being measured over the hemisphere opposite to that of its source (c.f., Boschert, Hink & Deecke, 1983). The apparent vertical orientations of the P1r and P300 factors would not lend themselves to such a situation. The N1 could potentially be due to a medial generator projecting laterally onto the contralateral hemisphere. However, the N1 is larger contralateral to stimuli supporting the contention that it is located over the originating hemisphere (since the hemisphere contralateral to the stimuli is the one primarily responsible for processing visual information).

Caution must also be observed in the difference between correlates and manifestations of a construct (Hockey, Coles & Gaillard, 1986). Since there was no experimental manipulation of anxiety or fear, it cannot be certain that the behavioral or evoked potential effects were not due to associated processes rather than the traits themselves. From the standpoint of understanding what these measures tell us about emotionality, identifying associated processes would also be important. At any rate, either way double dissociations provide strong support for dissociability.

A related concern is the distinction between state and trait. Whereas the underlying emotions theory is conceived primarily in terms of states, this experiment has relied on trait differences. It is possible that the observed effects are due to personality traits that predispose one to anxiety and fear but are not due to the states themselves. Regardless of whether the effects are due to state or trait differences, they provide strong evidence for the dissociation of anxiety and fear, whether directly or indirectly.

Finally, statistically derived factors are useful as estimates of the underlying potential waveforms but should not be taken at face value. Factors can misestimate the underlying waveforms for a number of reasons; on the other hand, PCA results do not arise <u>de novo</u> as all features reflect the originating dataset in some manner. A particular hazard is that potentials with similar time courses are likely to be conflated into a single factor. When a factor reflects multiple components, single channel estimates of laterality may miss effects present at other sites that are due to a component with a different topography. As usual, negative results do not necessarily indicate the absence of an effect.

The nature of the evoked potential correlates may be informative. For the most part, the evoked potentials did not respond to the task manipulation. This suggests that although the evoked potentials show a clear difference between the groups, the experimental tasks are not well-suited for tapping them. In the absence of established behavioral markers, the benefits of using a neuroimaging technique such as high-density ERPs become evident. First of all it confirms that these particular psychometric measures may indeed identify different dimensions of individual difference, even if more studies are required. The nature of the ERP effects also provides clues as to what future studies should examine.

The P300 is a well-studied component that has been proposed to reflect updating of a working memory representation of contextual probabilities (Donchin & Coles, 1988). It is not normally considered to display lateralized activity so it is uncertain whether the P300, or some other conflated component, is responsible. Although the P300 effect shows a laterality opposite to that expected (high trait anxious have a more right-lateralized topography), Figure 7 reveals that this effect is due to changes over the left hemisphere. The P300 link to anxiety is intriguing given that the hippocampus has been found to participate in this process (McCarthy, Wood, Williamson & Spencer, 1989), although the scalp-recorded potential appears not to have its source there (Polich & Squire, 1993). If the P300 is indeed responsible for this effect, it suggests that right hemisphere contextual working memory processes may be impaired in the highly anxious, as noted for OCD patients (Boone et al., 1991; Zielinski et al., 1991). On the other hand, the marginally significant nature of this effect suggests caution regarding it.

It is not known what the visual N1 represents exactly or where it is generated. In this case, the N1 localized to the temporoparietal junction, a region that has been implicated in local-global attention (Robertson & Lamb, 1991). This function is lateralized with the left hemisphere region mediating attention to local features and the right hemisphere counterpart mediating attention to global features. ERP studies of local-global attention have found a corresponding left-lateralized negativity for attention to local figures, although this was reported to peak at about 250 msec (Heinze, Johannes, Munte & Mangun, 1994; Heinze & Münte, 1993). It is possible that this evoked potential therefore represents increased attention to visual details in trait anxious participants. This would be in accord with a previous study that found increased attention to the local level in anxious participants (Tyler & Tucker, 1982).

The P1r is a newly described component whose nature is unclear at present (Tucker et al., 1994). It may be the same as the recently proposed visual P-SR component whose nature is equally unclear (Falkenstein, Hohnsbein & Hoorman, 1993). Its topography is suggestive of a parietal source which would implicate spatial attention functions, particularly since it displayed right-lateralization (Corbetta, Shulman, Miezin & Petersen, 1995). Such a connection would be intriguing in view of the possible connection between fearfulness and the Easterbrook spatial attention effect.

This study has a number of implications for clinical and emotion studies. It suggests that studies using the STAI and the FSS measures should strongly consider using both measures as they appear to tap different processes. They should also consider partialling out variance shared with STAI-trait from the FSS. The literature on effects of anxiety should also be reevaluated with respect to the possible role of fear. Anecdotal accounts that the Easterbrook effect is difficult to observe in the laboratory may be due to the use of the wrong measure (anxiety rather than fear). Likewise, the results suggest that the slowing effect of trait anxiety on reaction time is most clearly visible in the high trait fearful. Continued efforts to dissociate anxiety and fear behaviorally and neurally are strongly indicated.

This study also demonstrates how evoked potential measures might be used to examine issues of individual difference. A combination of psychometric and neural imaging methods may prove useful for clarifying some of the issues that have proven resistant to purely psychometric approaches (c.f., Canli et al., 1997; Fischer, Wik & Fredrikson, 1996). Moreover, the application of neurocognitive perspectives to individual differences research (Cloninger, 1987; Depue & Spoont, 1986; Gray, 1991; Zuckerman, 1984), is an area of increasing interest. Specification of individual differences in neurocognitive mechanisms could assist efforts to understand more macro levels of analysis. For such efforts, electrophysiological measures have the advantage of allowing many participants to be tested. The convergence of the descriptive power of psychometrics and the predictive power of neurocognitive models should enjoy increasing prominence in the near future.

Figure Captions

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FIGURE 1. Trait anxiety effect on task reaction times. For comparison's sake, comparable non-significant trait fearfulness chart included.

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FIGURE 2. Trait anxiety effects on task and visual field accuracy. For comparison's sake, comparable non-significant trait fearfulness chart included.

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FIGURE 3. Trait fearfulness effects on location reaction times. For comparison's sake, comparable non-significant trait anxiety chart included.

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FIGURE 4. Interaction of trait anxiety, trait fearfulness, task, and field of presentation.

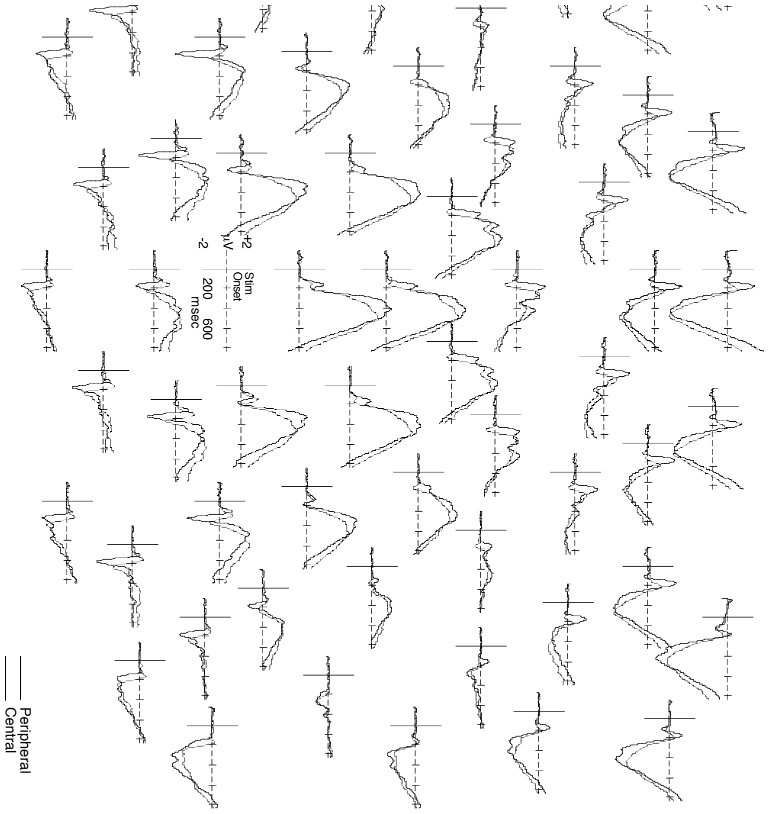

FIGURE 5. Grand average of responses to central and peripheral stimuli (using average reference transform). Waveform plots are laid out roughly topographically with the top of the figure corresponding to the front of the head. Channel 65 is the reference site activity estimated by the average reference procedure. The vertical line indicates

stimulus onset in each plot. Ticks on x-axis indicate 200 msec. intervals. The thick line indicates central stimuli and the thin line indicates peripheral stimuli.

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FIGURE 6. Scree test for PCA. Chart shows proportion of total variance of factors 7 through 20 of unrotated matrix. Arrow indicates elbow for retaining factors.

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FIGURE 7. Lateralized ERP effects related to trait emotionality. The grand average waveforms at the index sites for each factor are presented. Below each pair of grand averages is the time course of the relevant factor and its topography (for central stimuli). The factor waveform represents the portion of the LH index site waveform accounted for by the factor (collapsed over the central stimuli).

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FIGURE 8. Scatterplots for correlations between trait emotionality and lateralized ERPs. Scatterplots between STAI-trait or FSS (residualized by STAI-trait) and ERP factors. ERP measures consist of the difference between the site where the factor has the highest amplitude and the homologous site over the other hemisphere.

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FIGURE 9. Dipole localization results for the N1 (A) and P1r (B) factor solutions.

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Tables

Table 1.

STAI	FSS	n	STAI-t	FSS	FSS(res)
lo	**lo**	4	32.28	172.25	-71.29
lo	**me**	8	32.17	243.40	0.24
lo	**hi**	6	32.81	319.79	74.36
me	**lo**	7	41.74	170.33	-106.68
me	**me**	5	41.00	290.81	16.43
me	**hi**	6	39.32	334.88	66.42
hi	**lo**	7	50.55	238.56	-69.57
hi	**me**	5	53.12	320.39	3.19
hi	**hi**	6	54.39	417.42	95.69