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AN ANALYSIS ON THE INFLUENCE OF ANXIETY IN POST ERROR SLOWING

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Abstract

Anxiety disorders are among the most common mental disorders and affect 15.7 million Americans each year (Lépine, 2002, p. 4). Anxiety is associated with reduced productivity, physical distress, and other diseases such as depression. Anxiety could also be influential in error response (Compton et al., 2008; Luu et al., 2000; Robinson et al., 2007). Increased response time (RT) to respond to a stimulus following an error is known as post error slowing (PES). PES is widely attributed to increased caution following a mistake or cognitive adaptation to optimize behavior for correct responses in the future (Danielmeier & Ullsperger, 2011). Another theory to explain PES is that unusual responses - whether mistakes or accurate ones depending on which is common - will catch the participant's attention and distract them from their previous strategy leading to slower response times (King et al., 2010; Notebaert et al., 2009). This thesis examines the relationship between anxiety and post error slowing trends in a sample of young adults through linear mixed-effects (lme) modeling. Anxiety and demographic variables were included in a mixed linear model analysis to determine significant predictors of PES. A statistically significant positive association between anxiety and PES in this sample suggests that individuals with reported social anxiety experience an increased reorienting time following an error.

Introduction

Post error slowing has been previously explained by several causes including the popular cognitive control theory. This explanation attributes PES to strategic adaptation following an error to improve future performance. Newer research has suggested that the discrepancy between expectations and outcomes, rather than increased caution or better cognitive control, determines PES (Castellar et al., 2010). This conclusion is supported by several studies which found that lower frequency of erroneous responses corresponded to more drastic increases in PES (Castellar et al., 2010; King et al., 2010; Olvet & Hajcak, 2009). In a 2010 study by Castellar and colleagues, the high accuracy group exhibited significantly greater PES than the lower accuracy groups (Castellar et al., 2010). Steinborn's results support the theory that following an unusual response, participants need to reorient, a process that slows information processing for following trials (Steinborn et al., 2012). This thesis research was conducted to analyze the association between anxiety and reorienting time as indicated by PES trends.

Measures of anxiety were determined by participant scores on either of the widely used Beck Anxiety Inventory (BAI) and Brief Social Phobia Scale (Brief). The BAI is a 21 item self-report questionnaire with high internal consistency and retest reliability that is correlated with the Hamilton Anxiety Scale, $r(150)= 0.51$ (Beck et al., 1988). The BAI is a validated and reliable measure of anxiety symptoms and would serve as a general gauge of immediate anxiety. The Brief is an 11 item questionnaire that evaluates common symptoms of social phobia. It has high internal consistency and test-retest reliability (Davidson et al., 1991). The Brief aids the BAI's anxiety measurement by assessing anxiety-related avoidance and performance anxiety, common behavioral tendencies in individuals with high trait anxiety (Beck et al., 1988; Davidson et al., 1991). Such anxiety related avoidance may be expressed in PES trends.

The measure of PES was extracted from data on participants' response times on the Parametric Go/NoGo/Stop (PGNGS) computerized neuropsychological task. The PGNGS is a two sequence, three level task that increases in difficulty at each subsequent level. Participants were given the conditions of each level and asked to respond by pressing a key on a laptop keyboard only when those conditions were met. For the first sequence, the first level involves responding quickly and accurately to only two letters and disregarding any others. In the next level, participants are to respond to the same two letters but only when they alternate. If a letter is repeated, a response should wait until the other letter appears. The third level of the task measures impulse control. For this level, participants again respond to the same two letters but only if no stop sign appears after the letter. They are instructed to wait until the following letter to respond if there is no stop sign. In the second sequence of the task, the three levels remain the same, but there are three target letters instead of two. An earlier version of the PGNG task has been found to have strong validity and reliability (Langenecker et al., 2007). This analysis used data from the second level of both sequences: the two and three target Go/NoGo portions of the task.

Methods

The data used in this study was collected by Dr. Scott Langenecker and his team at the University of Illinois at Chicago. Participants were young adults between the ages of 18 and 30 (average age 23 years, standard deviation 3 years).

Table 1
Participant Counts for Diagnosis, Gender, and BAI anxiety level

Diagnosis	Count	Gender	Count	BAI anxiety level	Count
rMDD	33	Male	21	Low	38
HC	8	Female	30	Mid/High	13
BP	10				

Participant counts are shown for different groupings by diagnosis, gender, and BAI anxiety level (<21 is low, 22-35 is moderate, >35 is potentially concerning/high).

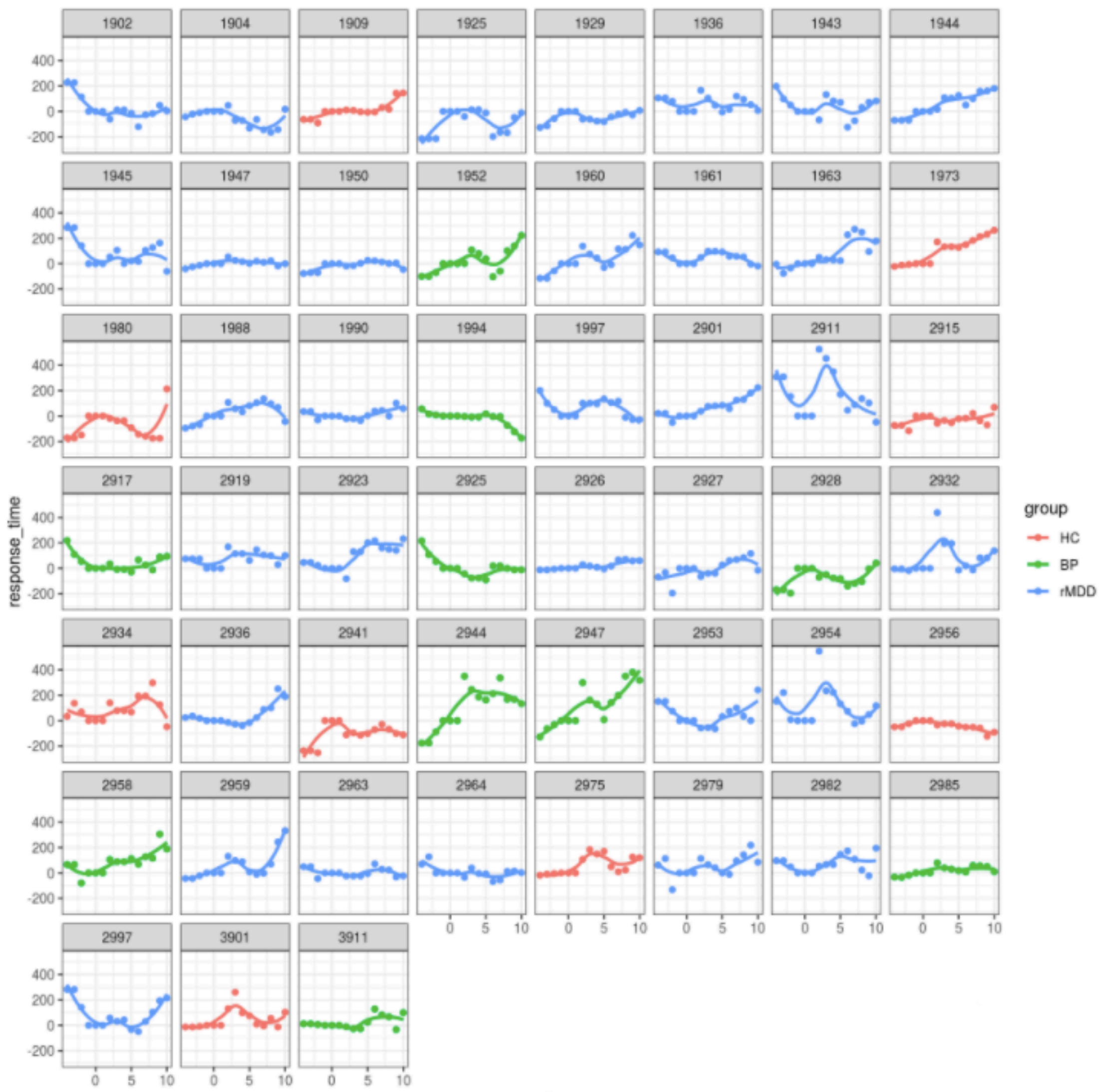
Response time measurements were extracted from data collected from participants during the two and three target levels of the Go/NoGo portion of the Parametric Go/NoGo/Stop (PGNGS) neuropsych task. To examine PES, at least seven total errors should be present in these two levels of the task (Walker et al., n.d.). The two and three target data were later pooled for analysis to increase the available sample size in the data.

In the initial stages of data cleaning, measures of response time were compiled for events prior to, during/the event of, and after the error. Any omissions in responses were computed by the scoring program as the average RT +1.5 times the standard deviation of participant RTs. Further cleaning of the data was done by checking for minimal attention to the task as evidenced by less than 50% overall accuracy and regular response times exceeding 1000 ms. If participants cared too little about the task and responded without regard to the instructions as evidenced by the previously stated criteria, their data would have been discarded from further analysis.

Since the PGNGS task was not made with the intent of studying PES, targets were often close to each other leading to pre and post error events commonly overlapping when measurements were extracted too distally from any singular error. Hence, after initial stages of analysis, it was decided that the focus of the analysis would be events -4 to 10 to avoid double counting in response time measurements while still examining early, middle, and late PES (Walker et al., n.d.). From the 212 people in the study with complete data, 51 participants met the criteria for number of errors (8 out of 53 HC, 33 out of 123 rMDD, and 10 out of 36 BP), and the rest were excluded from this study. The final sample diagnostic group counts are shown in Table 1. RTs were averaged across each event distance to generate an average pre and post error response for each of the 51 eligible participants (average error count: 10, SD: 3).

Figure 1

Participant Response Time Trends



Trends in zeroed response times in milliseconds were smoothed by a polynomial function for individual participants. The x-axis of each graph corresponds to the event number from 4 before to 10 after an error. Color codes correspond to diagnosis with red meaning healthy control, green signifying bipolar, and blue coding for remitted depressed. RT values above zero indicate a response time slower than what was recorded for the average error RT.

Since the PGNGS task does not measure a response time for each event, after the averages of each event distance were computed, the data was smoothed to fill any holes. Smoothing was completed by averaging response times from the single events before and after the hole. The average number of measurements that went into participant's response times for the events of interest is displayed in the table below

Table 2
Number of Measurements Incorporated to RTs by Event

Event number	Average number of contributing measurements before smoothing	Average number of contributing measurements after smoothing
-4	1.2	2.1
-3	0.5	1.7
-2	0	0.5
-1	0	9.6
0	9.6	9.6
1	0	9.6
2	0	1.9
3	1.9	4.7
4	2.7	5.4
5	0.8	5.0
6	1.5	3.4
7	1.1	4.3
8	1.6	4.0
9	1.2	3.8
10	0.9	3.7

A numerical representation of the number of responses that were incorporated into participant RT data both before and after smoothing are shown above.

Once smoothing was complete, initial analyses of the response time trends were conducted. To begin the initial analysis, the mean error RT was subtracted from the response time dataset for each participant to zero the plots. Participants were characterized as low (38), moderate (11), and potentially concerning (2) anxiety as determined by their score on the BAI. For initial analyses of anxiety groupings, the moderate and potentially concerning participant groups' data was analyzed in contrast to the low anxiety group. More initial analyses were conducted before an R program was written to conduct associative tests and to measure the normality of the data.

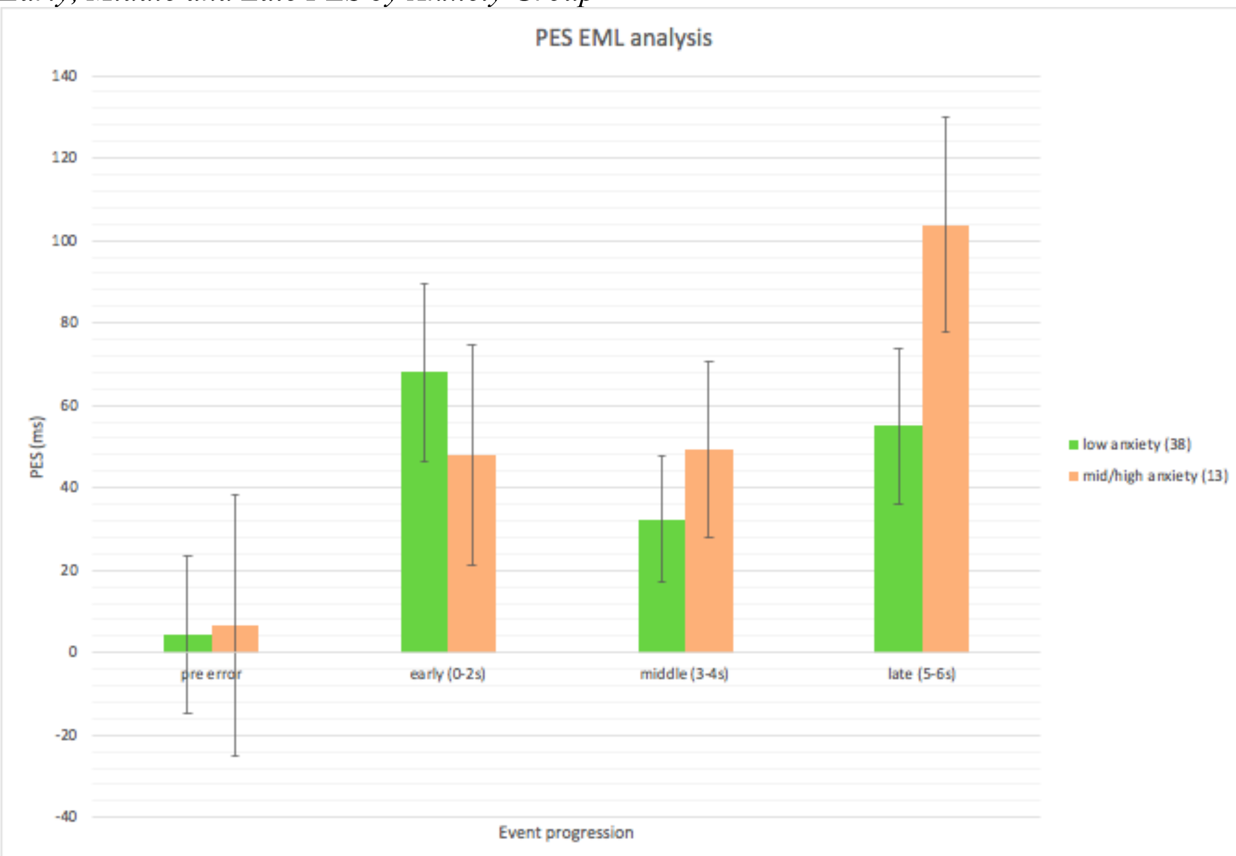
Several iterations of a linear mixed model based off of the research in the Bates et al. 2015 paper were run. Gender, handedness and years of education were not significant predictors of response times and were hence eliminated from further analyses. After an initial run of the model, the measure of anxiety was changed from the BAI to the Brief to see if there was a stronger predictive relationship between this anxiety measure and response times. Further fine tuning of the model was implemented, and the results and findings are discussed in the following section.

Results

Preliminary Analyses:

Figure 3

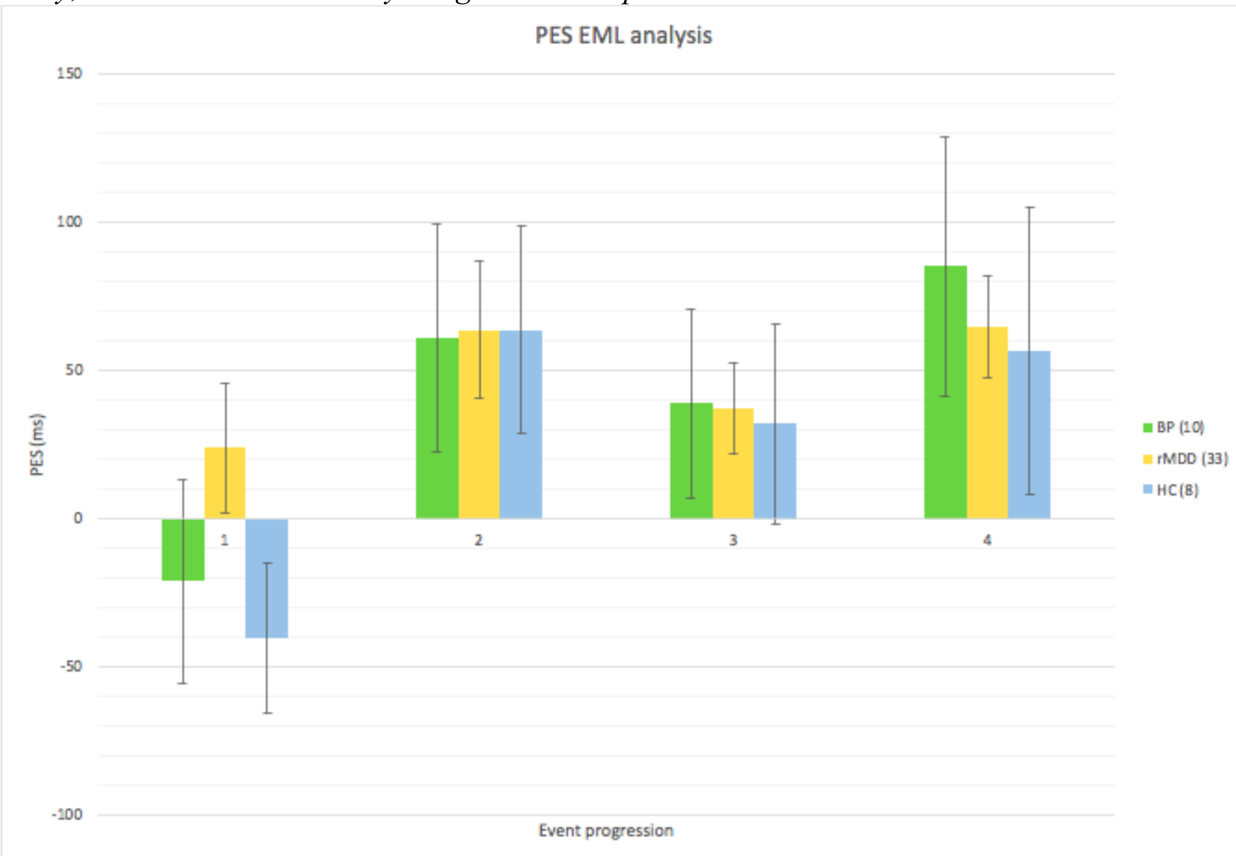
Early, Middle and Late PES by Anxiety Group



A visual representation of early, middle and late PES for the different BAI anxiety groupings is shown. Error bars indicate the standard deviation of average measurements for the appropriate anxiety grouping for the specified time interval.

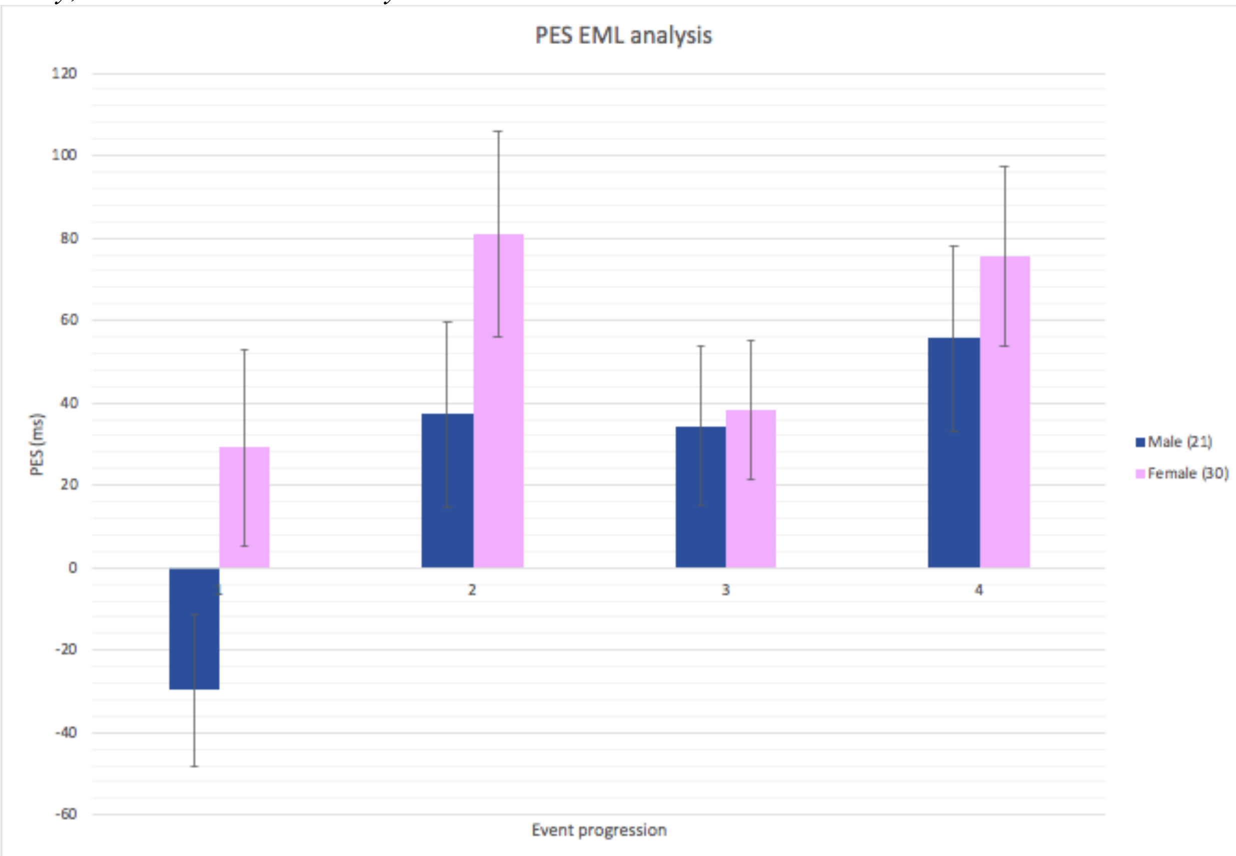
Figure 4

Early, Middle and Late PES by Diagnostic Group



A visual representation of early, middle and late PES for the different participant diagnoses is shown. Error bars indicate the standard deviation of average measurements for the appropriate diagnosis grouping for the specified time interval.

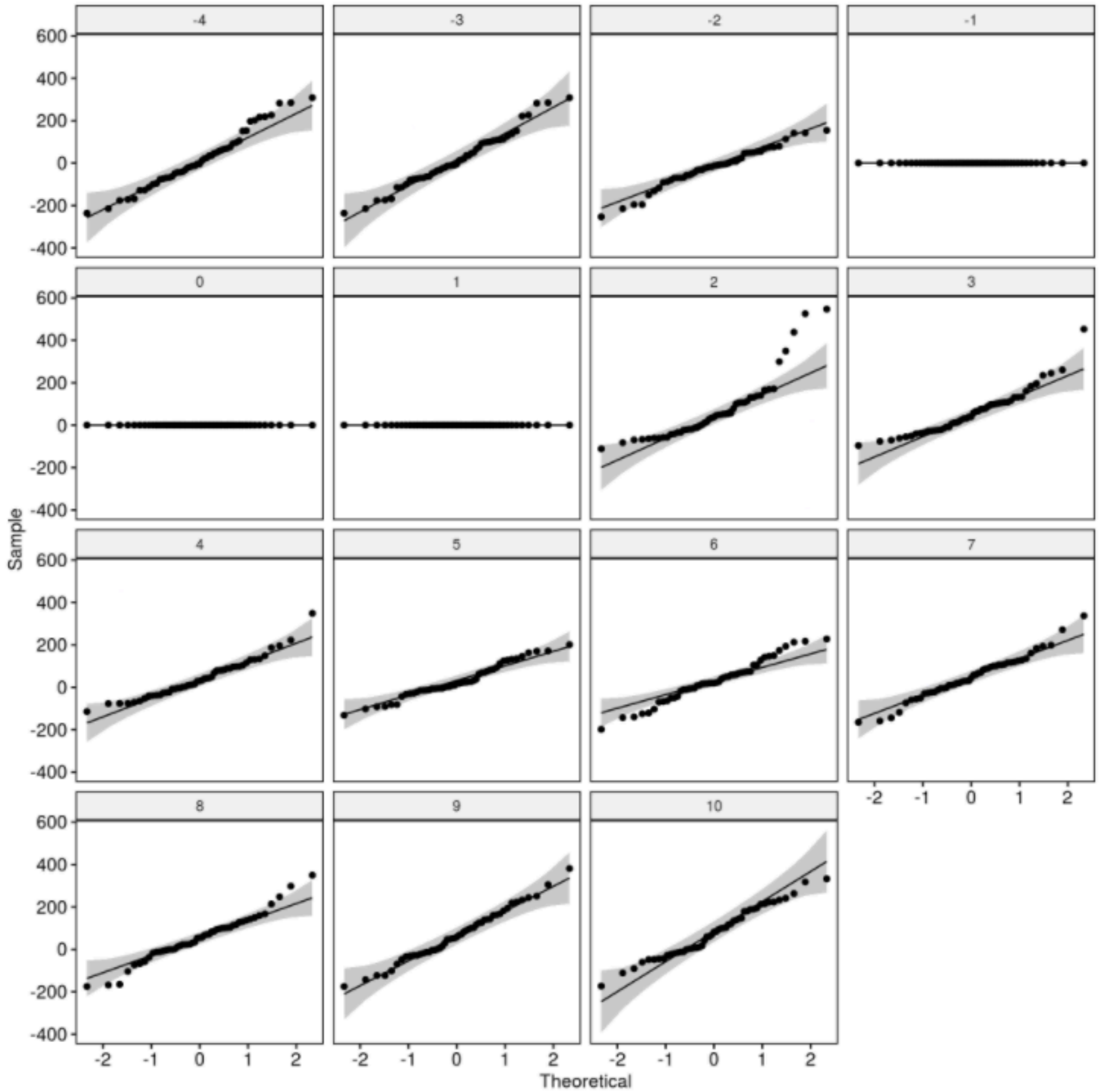
Figure 5
Early, Middle and Late PES by Gender



A gender analysis was also conducted to visualize any differences between male and female participants' response time trends. As before, error bars show the standard deviations of averages in the specified time interval.

Preliminary analyses did not show any significant differences in RTs between anxiety groupings, diagnostic groupings or genders at a 0.05 level as shown in Figures 3, 4, and 5.

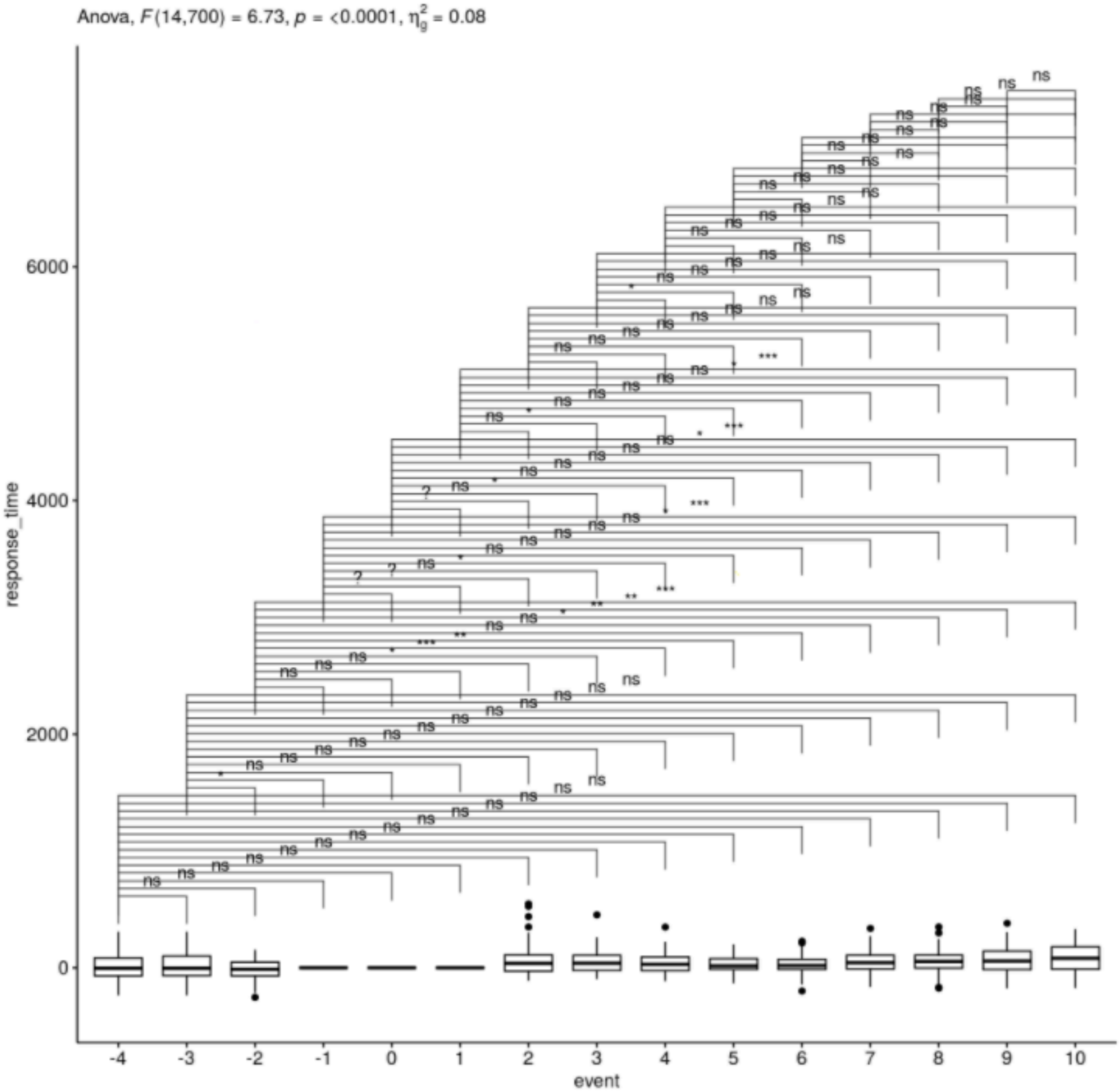
Main Analyses:
Figure 6
Test of Data Normalcy by Event



A graphic display of a test of normalcy for each event's response times is shown. Measurements outside the grey bounds such as those present in event 2 indicate deviations from a normal distribution in an event's response times. The deviation from normalcy in event 2 can be explained by the method of approximating RTs of missed responses (average + 1.5 times the standard deviation). The right skew here shows that this approximation could be improved to more accurately fill in for a missed response in future PGNGS scoring by reducing 1.5 SD to 1 SD.

Figure 7

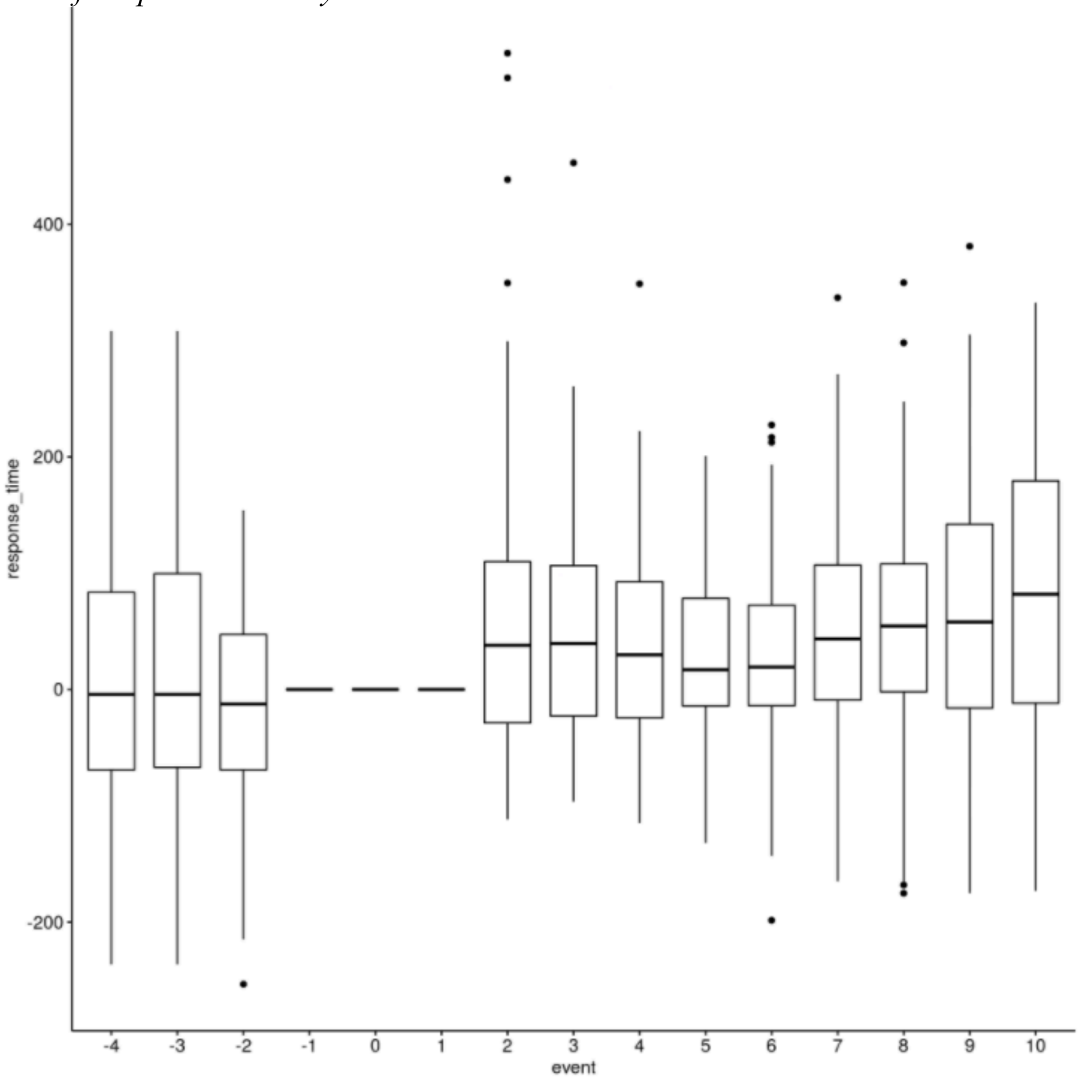
Statistical Differences Between Events



The statistical significance or lack thereof of differences between average event response times is overlaid on a box plot of event average RTs. Many event RTs are not significantly different (ns) due to high relative variability in response times and a small general upward trend in RTs.

Figure 8

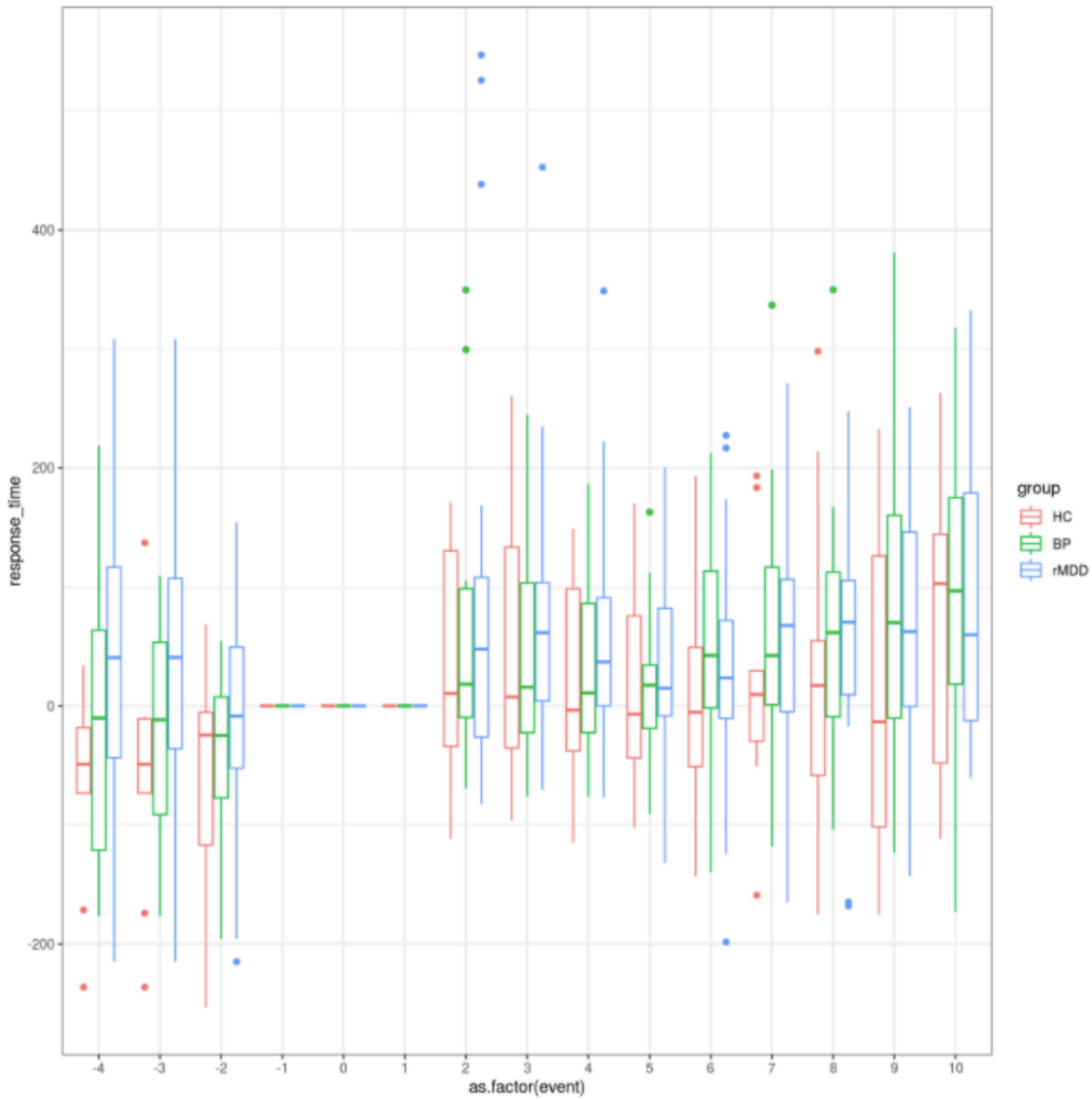
Box Plot of Response Times by Event



An enlarged bar graph of zeroed response times across events is shown. The general upward trend in mean RTs is a visual indication of PES. High outliers were often generated by the specified method for approximating the RT of a missed response, another indication that this method should be improved in the future by reducing the 1.5*SD addition.

Figure 9

Box Plots of Response Times by Event Separated by Diagnosis



Zeroed response times across events for each diagnosis group is shown. Diagnosis groups are color coded according to the following: Red- healthy control, Green- Bipolar, Blue- remitted depressed. There are no statistically significant differences between the diagnostic groups' response times for any of the events in question.

Table 3
Error Counts by Task Level

BAI anxiety Level	Participant count	2T average error count	SD	3T average error count	SD	Combined error average	SD
low	38	4	2	5	2	10	3
moderate/ potentially concerning	13	5	2	6	2	10	3

The average error counts and their respective standard deviations of the 51 participants' data are shown for the 2 and 3 target go/nogo portions of the PGNGS task as well as the two combined. No statistically significant differences were observed between the two participant anxiety divisions nor the two and three target go/nogo levels for each of the anxiety groupings.

Table 4
Table of Fixed Effects

	Estimate	Std. Error	t value
intercept	54.9	109.0	0.50
event	7.28	3.37	2.16*
BAI score	-0.86	1.07	-0.74
Brief score	1.98	0.83	2.37*
raceAsian	-2.19	38.8	-0.06
raceBlack/African American	62.0	22.3	2.73*
more than one race	19.5	29.5	0.65
race not reported	50.9	43.5	1.17
Not Hispanic/Latino	-18.5	25.5	-0.73
Left handed	-55.5	61.8	-0.90
Right handed	-70.6	61.7	-1.15
male	-15.8	15.9	-1.00
age	-5.88	3.34	-1.76
education	10.3	6.26	1.64
rMDD	14.2	28.0	0.51
BP	-20.3	34.7	-0.59

* significant at the $p<0.05$ level

The preliminary mixed linear model's fit to the data is described in the figure above. The column titled estimate shows the estimated numerical effect (in milliseconds) on the response times given the fixed effect. The t value indicates the level of statistical significance with values over 2 being significant at $p<0.05$ and marked by an asterisk.

In this iteration of the model, it was found that the BAI was not a significant predictor of PES trends. The lack of significance was an indicator that the traits associated with anxiety measured in the BAI are not influential in error response. The results of the preliminary model informed the switch of the primary measure of anxiety from the BAI to the Brief. Unlike the BAI, the Brief was significantly correlated with PES and measures avoidance and performance anxiety traits hypothesized to be expressed in PES (Beck et al., 1988; Davidson et al., 1991). In interpreting Tables 4 and 5, refer to the following example from the data in Table 4. In examining the fixed effect of response time, the preliminary model is reporting that if all other variables remain constant, the response time in milliseconds can be described by the equation RT=54.94+event7.28.

Table 5

Final Model Table of Fixed Effects

	Estimate	Std. Error	t value
intercept	-19.9	21.6	-0.92
event	4.89	1.42	3.42
Brief score	1.51	0.61	2.46
raceAsian	2.13	36.6	0.68
raceBlack/African American	40.7	18.2	2.24
more than one race	-7.07	27.0	-0.22
race not reported	46.6	37.7	1.24
BP	-1.36	28.6	-0.05
rMDD	10.8	24.4	0.44

In the final model, insignificant demographic data was removed from analysis to avoid collinearity with significant predictors. The only significant demographic variable was a race of "Black/African American," yet all races were included in the final model for comparison. Significant predictors of RT trends include event, Brief score, and a race of "Black/African American."

Discussion

The statistically significant positive association between event and RT validates the initial study assumption of the existence of PES. Though individual variability in response times is large, the data analyzed does indicate a general upward trend in response times following an error. This study augments the pool of available research supporting the existence and examining the nature of PES.

The insignificant association between BAI score and PES trends suggests that general anxiety as measured by the BAI is not influential in error response. This conclusion counters the hypothesis that general anxiety would have an effect on error response. However, the positive association between RT and anxiety as measured by the Brief suggests that social and/or avoidance anxiety could be influential in error response. The aspect of social anxiety influencing PES could be performance/ test taking anxiety or anxiety related avoidance. Since direct measures of test taking anxiety and anxiety related avoidance are less validated, social anxiety as measured by the Brief was used as a stand in for this study. Further research examining more direct measures of both test taking anxiety and anxiety associated avoidance in relation to PES would advance the results of this research.

The significance of a reported race of "Black/African American" in error response was further explored by running a chi squared test. The null hypothesis that race and diagnosis were independent was rejected ($p<0.0001$) indicating that racial distributions in diagnostic groups were not even. As was mentioned previously, diagnostic groups were altered in sample composition through error screening. However, diagnosis was not significantly influential in response time trends so further analysis is needed to explore the implications of race being significant in this instance.

Several aspects of the study are limiting in the analysis of PES. As is evident from the polynomial fit of RT data in figure 1, the participant response time data is not linear despite our model approximating it as such. The linear nature of the model is a limit of this study. In addition, since an error count of at least seven was necessary for PES analysis for data from the PGNGS task, higher accuracy individuals were removed during initial data screening reducing the number of available people for comparison. Previous research suggests that these high accuracy individuals display more dramatic and easily measurable PES that could not be characterized in this research. Diagnosis was also influential in final sample selection. Relative to the initial composition of the 212 person sample, the final 51 displayed a different diagnostic distribution.

Table 6

Diagnostic Composition of Original and Final Samples

Diagnostic group	Percentage in original 212 person sample	Percentage in final 51 person sample
HC	25	16
rMDD	58	65
BP	17	19

Higher rates of retention after error screening were seen in the BP and rMDD groups as compared to healthy controls. Relative to the original rMDD, HC, and BP populations in the 212 person sample, the final 51 had a significantly lower percentage of healthy controls and higher percentages of diagnosed individuals (8 out of 53 HC, 33 out of 123 rMDD, and 10 out of 36 BP).

Given the relative sample compositions before and after error screening, it can be concluded that a diagnosis of BP and rMDD is associated with lower accuracy on the PGNGS task. Further analyses with larger samples examining the extremes of both moderate and low accuracy populations in relation to diagnosis are needed to validate and extrapolate the results discussed in this study. Another limit of the study is that, in the PGNGS task, the participant is not explicitly alerted of any errors. PES could be more reliably analyzed if a buzzer or startling image alerted the participant of a mistake. The addition of such an alert in future iterations of the task would lower the possibility for distraction during and after an error. Modifications to account for discussed limitations would improve future studies examining the relationship between anxiety and PES.

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