Trait Anxiety Effects on Late Phase Threatening Speech Processing: Evidence from EEG

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Abstract:

The effects of threatening stimuli, including threatening language, on trait anxiety have been widely studied. However, whether anxiety levels have a direct effect on language processing has not been so consistently explored. The present study focuses on event-related potential (ERP) patterns resulting from electroencephalographic (EEG) measurement of participants' (n = 36) brain activity while they perform a dichotic listening task. Participants' anxiety level was measured via a behavioural inhibition system scale (BIS). Later, participants listened to dichotically paired sentences, one neutral and the other threatening, and indicated at which ear they heard the threatening stimulus. Threatening sentences expressed threat semantically-only, prosodically-only, or both combined (congruent threat). ERPs showed a late positivity, interpreted as a late positive complex (LPC). Results from Bayesian hierarchical models provided strong support for an association between LPC and BIS score. This was interpreted as an effect of trait anxiety on deliberation processes, which provides evidence of a fourth processing phase of an originally three-phasic model of emotional language processing.

Keywords: prosody, semantics, anxiety, emotion, cognition, electrophysiology

Introduction

Both anxiety and language processing are characterized by well-defined lateralization patterns. Anxiety has been widely associated to a dual processing pattern: while attention-related arousal and fear-related responses tend to involve greater right hemisphere (RH) processing, evaluation-related apprehension and inhibition-related responses tend to involve greater left hemisphere (LH) processing (Heller et al., 1997; Nietschke et al., 2000; Spielberg et al, 2013). According to current models of speech processing (i.e. dual stream model), speech comprehension recruits both LH and RH (Kemmerer, 2015). While more RH involvement for the slow rate suprasegmental processing of prosody and/or affect/attitude recognition is required, more LH involvement is required for fast rate segmental processing and/or lexical categorization (Belin et al., 2004; Liebenthal et al., 2010; Poeppel et al., 2008; Zatorre et al., 2002). These observations speak not only of general hemispheric activity, but also of very specific activity patterns and brain anatomical structures that, in many cases, are shared by language and anxiety processing. This opens the question of whether these processes simply co-occur, showing superficial similarities, or they actually interact with each other.

Previous research suggests that attention processing, such as that required for fine-grained spatial recognition or recognition of emotional prosody, might be strongly associated to fear arousal, and anxiety responses (Vuilleumier, 2005; Sander et al., 2005). At the same time, worry has been associated with appraisal processes characteristic of environmental evaluation aimed at threat detection, which can be understood as a behavioural inhibition system (BIS) that parses approach or withdrawal responses (McNaughton and Gray, 2000; Corr and McNaughton, 2012). Indeed, neuroimaging evidence indicates that higher levels of arousal are associated to early over-attention to threat, while higher levels of worry are associated to later over-engagement with threat (Spielberg et al., 2013). Hence, it is plausible that these responses are not only modulated by intrinsic affect (i.e. trait anxiety), but also depend on the type of information being processed (i.e. semantics or prosody) In this way, information type could potentially modulate over-attention to threat at early processing stages and over-engagement with threat at later processing stages.

Therefore, understanding these processes as multistage processes might be crucial. A two-stage model proposes that trait anxious personality is characterized by an over-active BIS, when attempting to resolve approach avoidance conflicts in a valuation stage (stimulus input) before a motivation stage (behavioural output) (Corr and McNaughton, 2012). However, this model does not give an account of potentially multifarious processes that might occur between valuation and motivation. A multistage model of anxiety (Bar-Haim et al, 2007) proposes that

anxiety develops through four processing stages: 1) pre-attentive threat evaluation, 2) resource allocation, 3) guided threat evaluation, 4) goal engagement system. Here, a valuation input can respond to pre-attentive stages, which can account for fear responses inducing rapid withdrawal (output), or fight-flight-freeze (FFFS) system responses (Corr and McNaughton, 2012); or can respond to resource allocation (output), which can lead to behavioural inhibition (or BIS engagement) in a threat evaluation stage. Likewise, a goal engagement system can account for a motivation output that occurs after BIS activation, for either approaching or withdrawing.

Interestingly, a multistep model has also been proposed for characterizing emotional language processing (Kotz and Paulmann, 2011). This model proposes three main stages: 1) early stage perceptual processing, 2) mid stage recognition processing, 3) late stage evaluation processing. An important aspect of this model is that it takes into account hemispheric differences of language and emotional processing. Early stages would respond to the processing of acoustic properties, where greater right hemisphere (RH) engagement would be associated to prosodic slower rate spectral information and more left hemisphere engagement (LH) would be associated to phonological (and by extension semantic) faster rate temporal information (Poeppel et al., 2008; Zatorre et al., 2002). Mid stages might involve the emotional recognition of stimuli, implying greater involvement of RH or LH depending on stimulus type and/or conveyed emotion (Schirmer and Kotz, 2006). Late stages would be associated to informational integration and evaluation of emotional stimuli (Kotz and Paulmann, 2011). An important step forward, therefore, would be including a fourth stage to this multistep model of language, which can account for motivation/goal-orientation processes associated to behavioural outputs in parallel to the multistage model of anxiety.

Nevertheless, to develop such a model, more evidence is necessary about how informational properties of language interact with intrinsic affect. Given that lexical items and prosody can convey emotional meaning at the same time (Nygaard et al., 2009; Schirmer and Kotz, 2003), the simultaneous recognition and integration of diverse informational properties is required, including the processing of segmental and spectral information, tonal and temporal information, and identification and categorization processes. As mentioned before, these aspects of language processing show different hemispheric asymmetries, which might be linked to anxiety related lateralisation in terms of how this information is recognized, integrated, and evaluated. Thus, a model of anxious lateralization (Heller et al., 1997) could be extended into a multistage model of anxiety (Bar-Haim et al., 2007), given early arousal-related over-attention to threat and later (and sustained) worry-associated over-engagement with threat differences (Spielberg et al., 2013).

Recent EEG evidence indicates that a hyperactive BIS, signalled by higher scores in BIS psychometric scales, presents a right frontal hemispheric pattern (Gable et al., 2018; Neal and Gable, 2017). However, some key theoretical notions cannot be overlooked. On the theoretical side, the proposed anatomic-physiological basis of BIS (so anxiety) is amygdala-hippocampal-septal route (Gray and McNaughton, 2000), which can modulate diverse cortical patterns depending on environmental conditions. Indeed, it has been proposed that the BIS limbic system might modulate higher processes such as worry and rumination through language systems (in particular left lateralized production/rehearsal), which could induce inhibitory control (Gray and McNaughton, 2000). Hence, while RH activity might mediate early (particularly motor) inhibitory control (McNaughton et al., 2013), there might be later LH mediated evaluation or deliberation processes. Previous EEG studies have observed left or bilateral frontal alpha activity associated with anxious apprehension as measured by worry (Heller et al., 1997; Nitschke et al., 1999), bilateral alpha for rumination-correlated BIS (Keune et al., 2012), and no hemisphericity patterns of delta or theta waves associated with BIS (De Pascalis et al., 2013). Indeed, recent models of anxiety (stated very generally), propose activation of dorsolateral pre-frontal cortex (dLPFC) inducing medial prefrontal cortex (mPFC) activity, together with hippocampus and insula, that will induce control over amygdala; where structures such as dLPFC show different lateralisation patterns (Robinson et al., 2019). Therefore, evidence suggests that BIS-related lateralization depends on task and stimulus (i.e. environmental conditions). Thus, higher BIS could particularly affect the processing of spoken threatening sentences at LH, especially if they contain threatening semantic information.

Given this, manipulating hemispheric input could reveal possible effects of anxiety on threatening speech processing at different processing phases. In other words, stimuli that are processed first by LH or RH might be affected differently depending on: 1) their language informational properties (i.e. semantics or prosody) and/or 2) participants' intrinsic lateralization differences when processing threatening stimuli (i.e. anxiety). Considering this, dichotic listening (DL) stands out as an ideal behavioural test to observe how anxiety-related hemispheric asymmetries might influence emotional language processing hemispheric asymmetries. This relates to the frequently observed phenomenon of a right ear advantage (REA) for non-prosodic language stimuli (Hugdahl, 2011); this implies participants answering faster and/or more accurately to stimuli presented at their right ear when compared to stimuli presented at their left ear. On the other hand, prosody, in particular emotional prosody, has been observed to present either a left ear advantage (LEA) or a diminished REA (Godfrey and Grimshaw, 2015; Grimshaw et al., 2003). Few dichotic listening (DL) experiments have

researched the effects of anxiety on emotional speech processing (Gadea et al, 2011). Instead, they either use speech/prosody as an emotion-eliciting stimulus, or use DL mainly as an attentional manipulation technique (Bruder et al., 2004; Leshem, 2018; Peschard et al., 2016; Sander et al., 2005).

To our knowledge, no EEG experiment has integrated trait anxiety measures with DL to investigate the effects of anxiety on threatening semantics and prosody. Behaviourally, using two DL experiments, it has been observed that anxiety does not induce clear ear (laterality) differences and only induces minor sentence type effects (Busch-Moreno et al., 2020). In that study, as sentences were relatively long (near 1800ms on average), experiments allowed ample time for deliberation and thus effects of trait anxiety obscured other possible effects. Given this, it might be that processing differences are not reflected in the behavioural output, but may be measured by electrophysiological activity. The first experiment from the aforementioned study was intended to allow deliberation, requesting participants to answer only after each sentence's end. Participants answered to threatening sentences of three types: 1) prosodic threat only, 2) semantic threat only, 3) both combined (congruent threat); all dichotically paired with neutral sentences. In a continuous second task, intended to measure possible attention effects, participants answered to the neutral pair instead. In the present study we aim to replicate this experiment by using the same procedure, but with newly recorded sentences and with trait anxiety measured by using the BIS scale from the Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ) (Corr and Cooper, 2016). In addition, by using the ERP technique we can provide fine-grained temporal information, crucial for testing our theoretical model, as laterality effects might been obscured behaviourally but could still be observed through EEG activity.

Given this setup and the previously discussed theory and research, we expect that higher levels of anxiety (higher BIS scores) will induce early over-attention to threat but mid-late over-engagement with threat. The first should be associated with anxiety induced arousal and BIS (McNaughton and Grey, 2000), which has been observed to be right lateralized (Heller et al., 1997; Neo et al., 2011). The second should be associated to a left lateralized or bilateral pattern (Nitschke et al, 1999), which might be due to mid-stage LH thought-induced (e.g. worry or rumination) evaluation and inhibition (Spielberg et al., 2013), but a later RH involvement associated to sustained anxiety-induced arousal. The stages of this processing time-course can be understood thusly: 1) pre-attentive (50-100ms), 2) attentive (150-250ms), 3) evaluative (250-500ms), 4) orientative (500-750ms). Following multistep model predictions: the first stage should show a bilateral pattern for language, as early sensory processing of language

might require the use of both hemispheres as prosody and semantics (even if neutral) need to be simultaneously processed. The second stage should be lateralized as a function of stimulus type, modality and emotion expressed. The third stage requires bilateral involvement due to evaluation and integration of different types of stimulus and emotion. The fourth stage we propose here should show an initial bilateral involvement with stronger RH persistent activity. This additional later stage can be understood as a deliberation phase, where participants decide (orientate) their responses to emotional stimuli.

Following previous predictions we specify the following hypotheses: 1) Early (~100ms) and Mid-early (~200ms) effects of anxiety on speech processing (Pell et al., 2015), where over-attention to threat will show stronger RH involvement for prosody, facilitating detection. 2) Mid-late stage (~400ms) anxiety effects on LH due to over-engagement with threat (Spielberg et al., 2013); this should particularly affect semantic stimuli by slowing down their processing. 3) A late stage (~600ms) effect of anxiety on goal orientation (Bar-Haim, 2007), where both LH and RH (more strongly) should be involved. This could be the results of a worry-arousal loop (McNaughton and Gray, 2000) due to continued exposure to threatening stimuli. In other words, verbal repetitive thinking could take prevalence at this stage due to over-engagement with threat (Busch-Moreno et al., 2020). No specific ERPs are predicted, as present research has no direct precedents in the literature. Hence, it is not clear whether observed ERPs, and their amplitude differences by condition, will be coincidental or not with those observed in previous research.

Methods

Participants

Participants (mean age = 28.6, age range = [19, 54], 19 females) were recruited using Sona Systems (sona-systems.com). Only participants reporting being right-handed, having English as first language, without hearing problems and with no history of neurological/psychiatric disorders were recruited. Participants were remunerated £7.5/hour rate. All participants were informed about their rights, including those regarding their data (protected under GDPR protocols), and gave their informed consent before participating. They received a debriefing statement at the end of the experiment.

Materials

Four types of sentences were recorded: Prosody (neutral-semantics and threatening-prosody), Semantic (threatening-semantics and neutral-prosody), Congruent (threatening-semantics and threatening-prosody), and Neutral (neutral-semantics and neutral-prosody). This resulted in 52 recorded sentences per threatening category and respective Neutral pairs (324 in total). Previous to this, sentences were extracted from movie subtitles by matching them with a list of normed threatening words from the extended Affective Norms for English Words (ANEW) (Warriner et al., 2013). For the present study, any word over 5 points in the arousal scale, and below 5 points in the valence and dominance scales was considered semantically threatening. Every word with less than 5 arousal points and between 4 and 6 valence points was considered semantically neutral. Words' frequencies were extracted from SUBTLEX-UK (van Heuven et al., 2014), only sentences containing words with Zipf log frequencies over 3 were included.

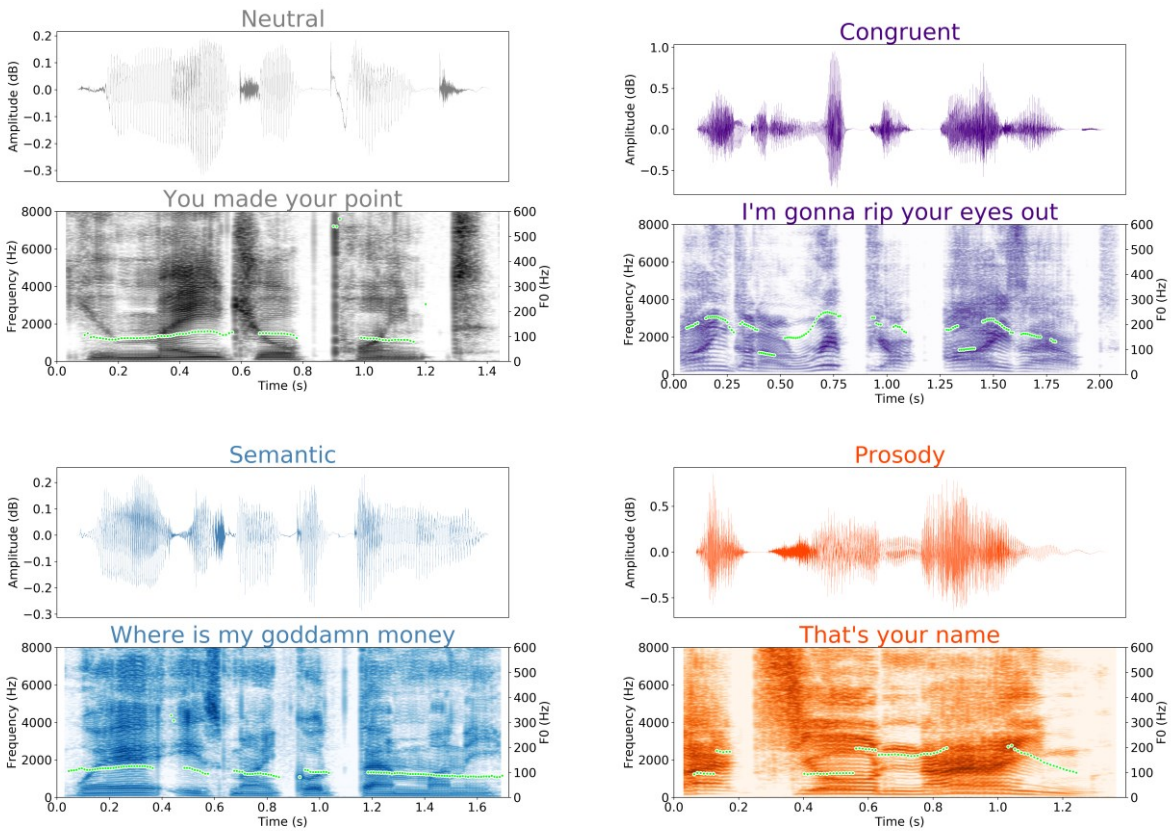

Figure 1. Examples of sentences with different semantic content and prosody. Top of each image: oscillogram showing amplitude changes. Bottom of each image: spectrogram showing frequency changes. Top left: neutral prosody and neutral semantics (Neutral). Top right: threatening prosody and threatening semantics (Congruent). Bottom left: neutral prosody and threatening semantics (Semantic). Bottom right: threatening prosody and neutral semantics (Prosody). Green dots indicate fundamental frequency (F0) contours.

Table 1. Average number of words, duration and reaction time per stimulus type

Type	Words Threat	Words Neutral	Stimulus Duration	Reaction Time
Congruent	4.63	5.63	1838.63	522.37
Prosody	4.24	4.93	1558.25	601.20
Semantic	4.43	4.89	1543.53	593.40

Table 2. Means from BEST comparisons for ANEW norms and acoustic measures

Arousal					Median Pitch				
Category	**Mean**	**SD**	**HDI 5%**	**HDI 95%**	**Category**	**Mean**	**SD**	**HDI 5%**	**HDI 95%**
Neutral	3.55	0.08	3.41	3.68	**Neutral**	101.38	0.7	100.29	102.62
Congruent	6.13	0.09	5.97	6.28	**Congruent**	167.25	2.55	163.06	171.35
Prosody	3.8	0.07	3.68	3.92	**Prosody**	175.85	2.16	172.17	179.23
Semantic	6.26	0.09	6.1	6.4	**Semantic**	102.01	0.7	100.89	103.15
Valence					**Hammarberg Index**				
Category	**Mean**	**SD**	**HDI 5%**	**HDI 95%**	**Category**	**Mean**	**SD**	**HDI 5%**	**HDI 95%**
Neutral	5.43	0.05	5.34	5.5	**Neutral**	21.09	0.52	20.32	22.04
Congruent	2.88	0.13	2.68	3.11	**Congruent**	7.93	0.54	6.96	8.79
Prosody	5.5	0.05	5.42	5.58	**Prosody**	7.85	0.41	7.25	8.61
Semantic	2.75	0.12	2.55	2.94	**Semantic**	21.2	0.57	20.28	22.2

Table 3. Effects of acoustic measures and emotional norms on threat ratings

Prosody				
Measure	**Mean**	**SD**	**HDI 5%**	**HDI 95%**
Median Pitch	0.033	0.003	0.029	0.037
Hammarberg Index	-0.113	0.013	-0.134	-0.091
Arousal	0.007	0.105	-0.167	0.168
Valence	-0.074	0.158	-0.319	0.199
Semantic				
Measure	**Mean**	**SD**	**HDI 5%**	**HDI 95%**
Median Pitch	-0.012	0.010	-0.029	0.004
Hammarberg Index	0.028	0.014	0.002	0.050
Arousal	0.518	0.083	0.385	0.653
Valence	-0.624	0.079	-0.755	-0.497

Sentences were recorded in an acoustically isolated chamber with a RODE NT1-A1 microphone. The speaker was instructed to speak in what he considered his own threatening/angry or neutral voice for recording Prosody/Congruent and Semantic/Neutral sentences respectively. All threatening sentences were paired with a different Neutral sentence of similar length, minor increases of sentences' silences (up to 40ms) were applied to make paired sentences' durations match perfectly; see Table 1 for a general summary. Figure 1 shows oscillograms and spectrograms of four sentences used as stimuli. Threatening prosody has been observed to align with hot anger (Banse and Scherer, 1996; Hammerschmidt and Jürgens, 2007) and can be defined mainly by pitch and roughness. Thus, we focused only Median Pitch (median each sentence's fundamental frequency) and Hammarberg Index (difference between 0 to 2000 and 2000 to 5000 frequency ranges). These acoustic measures can capture pitch (fundamental frequency) and voice quality variation respectively, and were extracted from sentences with Python's Parselmouth interface to Praat (Jadoul et al., 2018). Acoustic measures were compared by using BEST (Kruschke, 2013), but using $SD \sim Exponential\ (\lambda = 2)$ instead of uniform distributions. All models were sampled with MCM and used 1000 tuning samples and 1000 samples, convergence and sampling were excellent for both models ($\hat{R} \cong 1$, ESS > 400, BFMI > 0.8). As very clear in the Table 2, sentences containing threatening prosody have higher pitch (median pitch) and lower voice quality (Hammarberg index, i.e. more roughness) than sentences without threatening prosody. For both measures, Prosody and Congruent distributions greatly overlap and Semantic and Neutral sentences almost completely overlap.

In addition, we collected sentences threat ratings post-experimentally, for further confirming effects of both acoustic measures and ANEW norms. Ratings were given by 10 participants for 54 Prosody and 54 Neutral sentences (total number of Prosody and Neutral) in a 9-points Likert scale (0 = no threatening at all, 8 = very threatening). The same procedure was followed for the 54 Semantic sentences together with the same 54 Neutral sentences in a second rating session by 10 participants. Ratings were analysed by using a hierarchical Ordered-logistic model, with subjects as a varying intercept, eight scale cutpoints and normal priors (equivalent to L2 regularisation) for non-varying slopes for Pitch, Roughness, Arousal and Valence. The full model and plots can be found in our OSF repository (https://osf.io/n5b6h/?view_only=358e8b2d52684c92ac63aded03b22325). As is clear in Table 3, Prosody sentences were rated as more threatening (m = 5.01 points) than Neutral sentences (m = 1.13 points) as a function of increases in Median Pitch and decreases in Hammarberg

Index, but with almost no association with Arousal or Valence norms. As expected, Semantic sentences (m = 5.6 points) were also rated as more threatening than Neutrals (m = 1.29 points) as a function of an Arousal increase and a Valence decrease, with a negligible association with Median Pitch and Hammarberg Index measures.

Procedure

Participants were introduced to the recording room (electrically and sound isolated chamber), signed consent, and sat at 1m distance from a 20" screen used to display all tasks via PsychoPy2 (Peirce et al., 2019). Next, participants provided their demographic information (age and sex) and completed the BIS and FFFS questionnaires. Participants' head dimensions were measured and EEG caps of according size were placed and centered, conductivity gel was placed and the Biosemi 64 Ag/Cl electrode system (biosemi.com) was connected. Impedance levels were kept below 20Ω and electrodes were checked to be working properly. While EEG recording, participants completed the direct-threat task and indirect-threat tasks, where they answered at which they heard a threatening sentence pair by pressing left or right arrows on a keyboard (as fast and accurately as possible) only after the stimulus finished playing and a target symbol appeared on screen. In the indirect-threat task they answered to the neutral pair instead. Participants heard sentences twice such that a threatening sentence was presented once at each ear. Participants were requested to swap response hand every other block of 18 sentences Staring hand, ear and task were counterbalanced. Participants were allowed to rest by the end of each block.

EEG Data Processing

EEG recordings were pre-processed using Python's MNE package (Gramfort et al., 2014). A completely automated pre-processing pipeline was implemented, based on Jas et al.'s (2018) method. This consisted in the following steps: 1) Importing data, checking events and fixing if misplaced. 2) Set data to average reference (Dien, 1998; Lei and Liao, 2017). 3) Preparing data for independent component analysis (ICA) only: low-pass filtering at 40hz to avoid aliasing artifacts, down sampling to 256hz, high pass filtering at 1hz for better artifact detection, and automatic rejection of noisy segments based on the Autoreject MNE package (Jas et al., 2017; Winkler et al., 2015). 4) Computing ICA components by using python Picard package (Ablin et al., 2017). 5) Removing components that are highly correlated with noise at

Fpz channel to remove EOG artifacts from data. 6) Applying average reference to raw data (Dien, 1998; Lei & Liao, 2017) with excluded EOG artifacts and applying first a high pass (0.1hz) and later a low pass (100hz) filter (Luck, 2005; VanRullen, 2011; Widmann et al., 2015). 7) Epoching data from 0-1000ms using a 100ms baseline (10% of epoch), downsamplig to 512hz, and applying automatic detection, repairing and rejection of noisy epochs by using Autoreject's Bayesian optimization (Jas et al., 2017). 8) Applying baseline correction (baseline subtraction) (Luck, 2005; Tanner et al., 2015), as integrating the baseline into the model as a regressor (Alday, 2019) could be detrimental for convergence and precision in this particular case. 9) Extracting trial by trial mean amplitudes at 4 a priori defined time windows: 50-150ms, 150-250ms, 250-500ms, 500-750ms; these time windows cover the time-windows proposed by the multistep model (Kotz and Paulmann, 2011), plus our proposed fourth time-window. ERP and scalp plots of processed data were produced using the MNE package.

Data Analysis

Figure 2 shows the model used for EEG data, the diagram is based on Kruschke's (2015) and Martin's (2018) model specification and presentation, and their guidelines on robust regression. The model was sampled using Markov Chain Monte Carlo (MCMC) No U-turn Sampling (NUTS) as provided by PyMC3 (Salvatier et al., 2016). All models were sampled with two chains of 2000 tuning steps and 2000 samples, and initialised using automatic differentiation variational inference (ADVI) as provided by PyMC3. Plots of results were produced using Arviz (Kumar et al, 2019) and Matplotlib (Hunter, 2007). Results were assessed using a region of practical equivalence (ROPE) method (Kruschke, 2015; Martin, 2018), where high posterior density (HDI) intervals were considered as presenting a considerable difference when far away from ROPEs defined as 1SD to 2SDs around zero.

The core idea of the model is to pool apart data from the individual level of subjects and items, so we can focus on group level slopes at each single interaction point. Given this, pooling at the electrode level through a normal non-varying prior helped us to define an offset for the other reparametrized priors (e.g. McEalreath, 2020), which do not contain individual location parameters. In this way we could obtain intercepts from each electrode and improve sampling and convergence in a substantial manner. To be consistent with previous research, we did not include FFFS rating in the analyses, as our main focus is on trait anxiety and not on trait fear. Fear measures (FFFS) were collected as they could be required for comparison in future analyses. See our OSF repository for behavioural models (https://osf.io/n5b6h/?view_only=358e8b2d52684c92ac63aded03b22325).

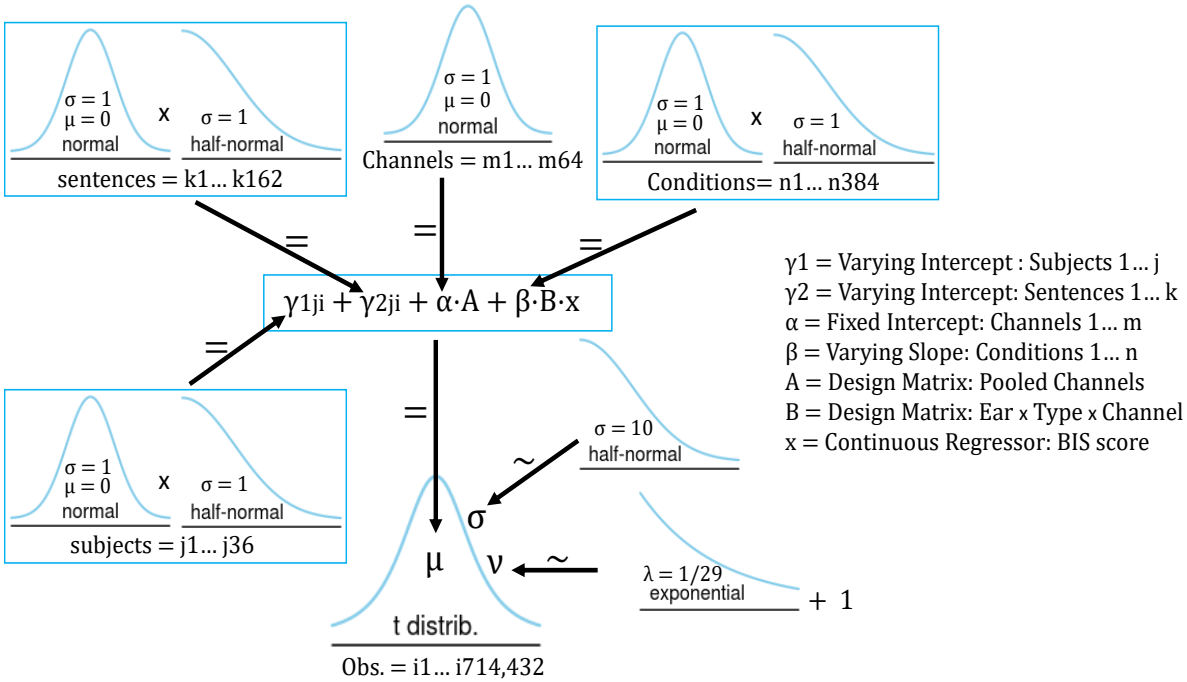

Figure 2. The diagram shows the prior distributions used for robust regression on amplitude. Arrows indicate the relationship between a parameter and priors/hyperpriors, where tilde (~) indicates a stochastic relationship and equal (=) indicates a deterministic relationship. Observations in the likelihood distribution are equivalent to mean amplitude at each single trial.

Results

Behavioural Analyses

All models sampled well, showing excellent convergence, with $\hat{R} \cong 1$ and ESS > 200 for all parameters, and good energy transitions for all chains (BFMIs > 0.6); all summaries and plots can be found in our open OSF repository. Table 1 and 2 summarise accuracy results from direct- and indirect-threat conditions. Note that these results consider BIS slopes (in log-odds) across all conditions, and all posterior distributions overlap zero, as clearly indicated by the HDI intervals. These results mainly indicate that BIS had no certain influence on accuracy. Even so results not including BIS main effect posterior indicate more certain classic DL effects, we opted out for presenting only posterior distributions addressing all effects, as low-level effects influence should not be disregarded. For these additional results and plots, please see our OSF repository.

Table 4. Direct-threat Accuracy Estimates

Type	Ear	BIS Score	Posterior Mean	Posterior SD	HDI 5%	HDI 95%	Probability%
Semantic	Left	1	-0.01	0.02	-0.04	0.03	49.81
Prosody	Left	1	-0.01	0.02	-0.05	0.02	49.66
Semantic	Right	1	0.00	0.02	-0.03	0.03	49.93
Prosody	Right	1	0.01	0.02	-0.02	0.04	50.29
Semantic	Left	55	-0.42	1.08	-2.03	1.45	39.67
Prosody	Left	55	-0.74	1.06	-2.48	0.94	32.20
Semantic	Right	55	-0.15	0.94	-1.61	1.39	46.24
Prosody	Right	55	0.63	0.92	-0.88	2.07	65.19

Table 5. Indirect-threat Accuracy Estimates

Type	Ear	BIS Score	Posterior Mean	Posterior SD	HDI 5%	HDI 95%	Probability%
Semantic	Left	1	-0.008	0.017	-0.037	0.018	49.80
Prosody	Left	1	0.026	0.017	0.000	0.056	50.66
Semantic	Right	1	-0.006	0.014	-0.030	0.015	49.84
Prosody	Right	1	0.014	0.014	-0.009	0.038	50.36
Semantic	Left	55	-0.444	0.925	-2.059	1.013	39.07
Prosody	Left	55	1.441	0.947	-0.009	3.089	80.86
Semantic	Right	55	-0.344	0.782	-1.647	0.852	41.49
Prosody	Right	55	0.793	0.786	-0.474	2.103	68.85

Table 6. Direct-threat Accuracy Estimates

Type	Ear	BIS Score	Posterior Mean	Posterior SD	HDI 5%	HDI 95%
Semantic	Left	1	3.20	0.40	2.54	3.84
Prosody	Left	1	3.25	0.39	2.62	3.90
Semantic	Right	1	2.79	0.33	2.25	3.35
Prosody	Right	1	3.04	0.34	2.49	3.60
Semantic	Left	55	176.09	21.76	139.95	211.20
Prosody	Left	55	178.50	21.64	143.94	214.60
Semantic	Right	55	153.21	18.25	123.59	184.04
Prosody	Right	55	167.04	18.87	137.08	198.26

Table 7. Indirect-threat Accuracy Estimates

Type	Ear	BIS Score	Posterior Mean	Posterior SD	HDI 5%	HDI 95%
Semantic	Left	1	4.37	0.41	3.71	5.06
Prosody	Left	1	4.29	0.41	3.64	4.96
Semantic	Right	1	4.23	0.35	3.65	4.79
Prosody	Right	1	3.79	0.35	3.22	4.35
Semantic	Left	55	240.48	22.47	204.31	278.46
Prosody	Left	55	235.85	22.29	200.14	272.72
Semantic	Right	55	232.38	19.09	200.92	263.32
Prosody	Right	55	208.63	19.03	177.11	239.50

Results from RT data also replicate our previous experiment. Tables 3 and 4 summarise results from direct- and indirect-threat conditions respectively. Note the large increase in estimates from lowest BIS scores to highest BIS scores, with HDIs well apart from each other. When intercepts are taken into account, the Direct-threat estimates portray an average effective increase of ~175ms from lowest (1 point) to highest (55 points) BIS score by Prosody at the left ear, and ~164ms at the right ear. While for Semantic the increase is ~172ms at the left ear and ~150ms at the right. The apparent left ear advantage for Semantic can be discounted due to HDI overlap. However, overall, RTs were the shortest for Congruent. Indirect-threat results are similar, excepting that in this case slower responses are only for Semantic. For more details on these additional patterns see our OSF repository.

EEG Analyses

All models sampled well, showing excellent convergence, with $\hat{R} \cong 1$ and ESS > 300 for all parameters, and good energy transitions for all chains (BFMIs > 0.6). Main results indicate that in both the direct- and indirect-threat conditions, the effects of BIS were concentrated on window4 (500-750ms), irrespective of ear or sentence type. However, intercepts indicate smaller but clear general effects at all time-windows (Figure 7). Hence, for brevity, we will only present results from the direct-threat condition. All other results' summaries and plots can be found in our OSF repository (https://osf.io/n5b6h/?view_only=358e8b2d52684c92ac63aded03b22325). Figure 3 gives an account of EOG activity and raw average amplitude across electrodes given BIS level (median

split), and Figure 4 shows raw averages of ERPs' topography by BIS score tertiles (Low: [1,15], Mid: [16:28], High: [29:55]).

Figure 5 shows the two electrodes showing maximal increases from the lowest BIS score (1 point) to the highest BIS score (55 points). Plots represent amplitude waves as resulting from a robust regression (Student-t observed distribution) using sampled time-points (286: 26 baseline, 256 epoch) as varying intercepts and as varying slopes (sample by BIS score), using reparametrized normal priors. Models, sampled with NUTS (1000 tuning, 1000 samples) passed all convergence criteria as main models. Although intended for display, these analyses further corroborate strong BIS effects at late time-windows, showing a clearer and stronger late positive complex (LPC) at the left hemisphere. Thus, earlier general effects observed in average ERP waves (Figures 3 and 4) and intercepts (Figure 7) are not present when accounting for BIS. This is strongly supported by varying slopes' estimates (Figure 7's bottom image).

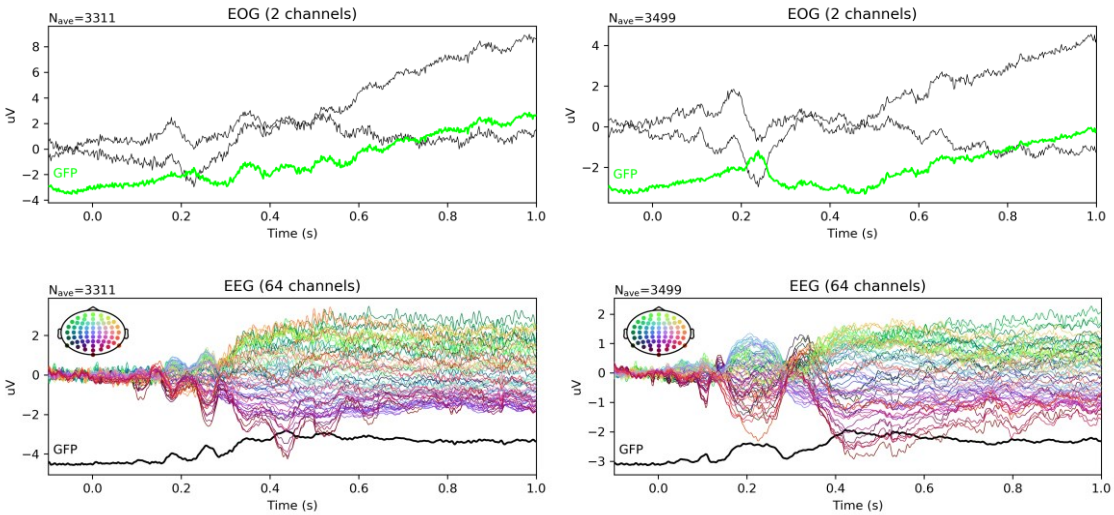

Figure 3. Upper panels show EOG activity for high BIS (left) and low BIS (right). Bottom panels show high BIS (left) and low BIS (right) grand averages across all electrodes. Note that polarities of EOG and EEG are aligned and baselines tight around zero amplitude; so, drifts are not artefactual (see: Luck, 2014).

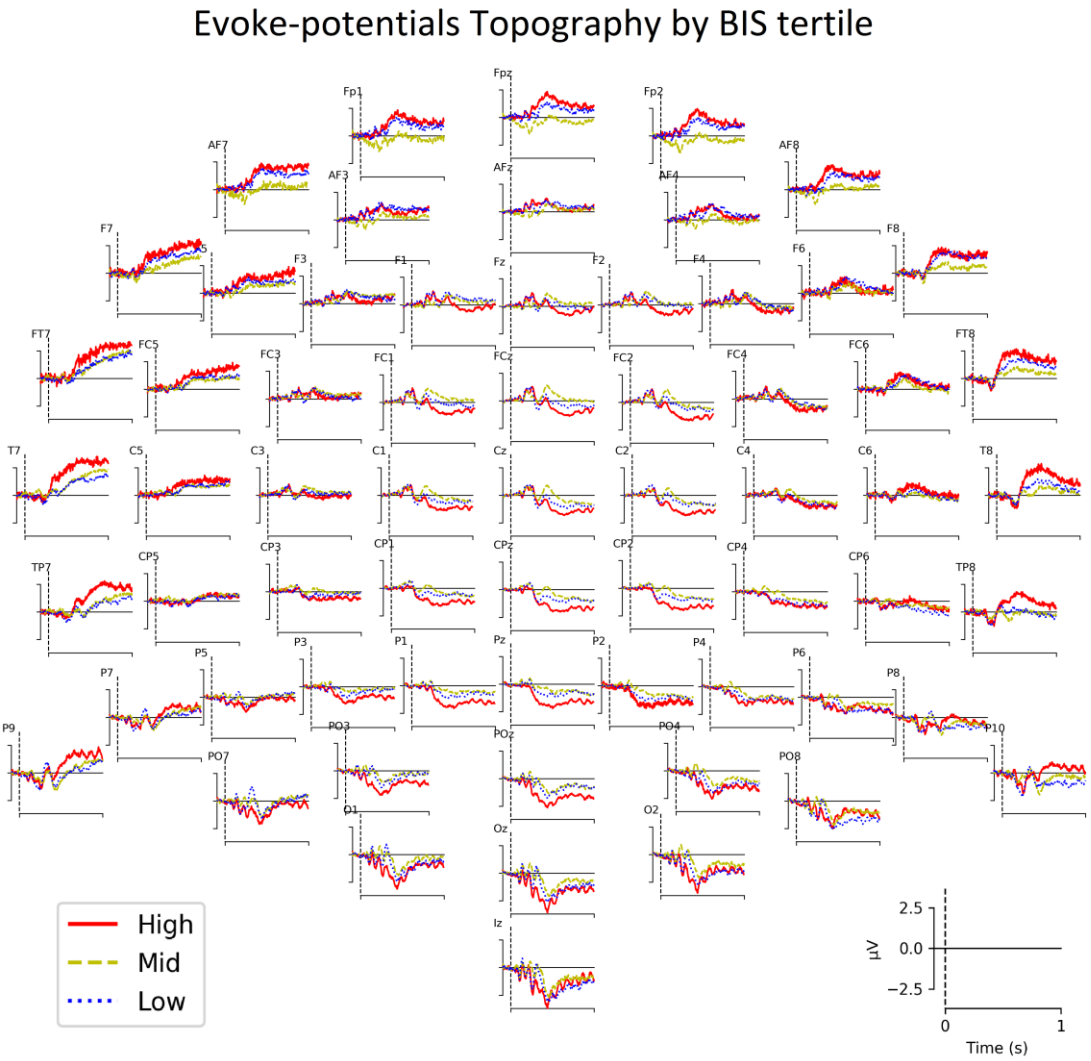

Figure 4. Scalp distributions of ERPs. Red solid line: High BIS score (over 28 points). Yellow dashed line: Mid BIS score (between 16 and 28 points). Blue dotted line: Low BIS (below 16 points). Waves are raw averages.

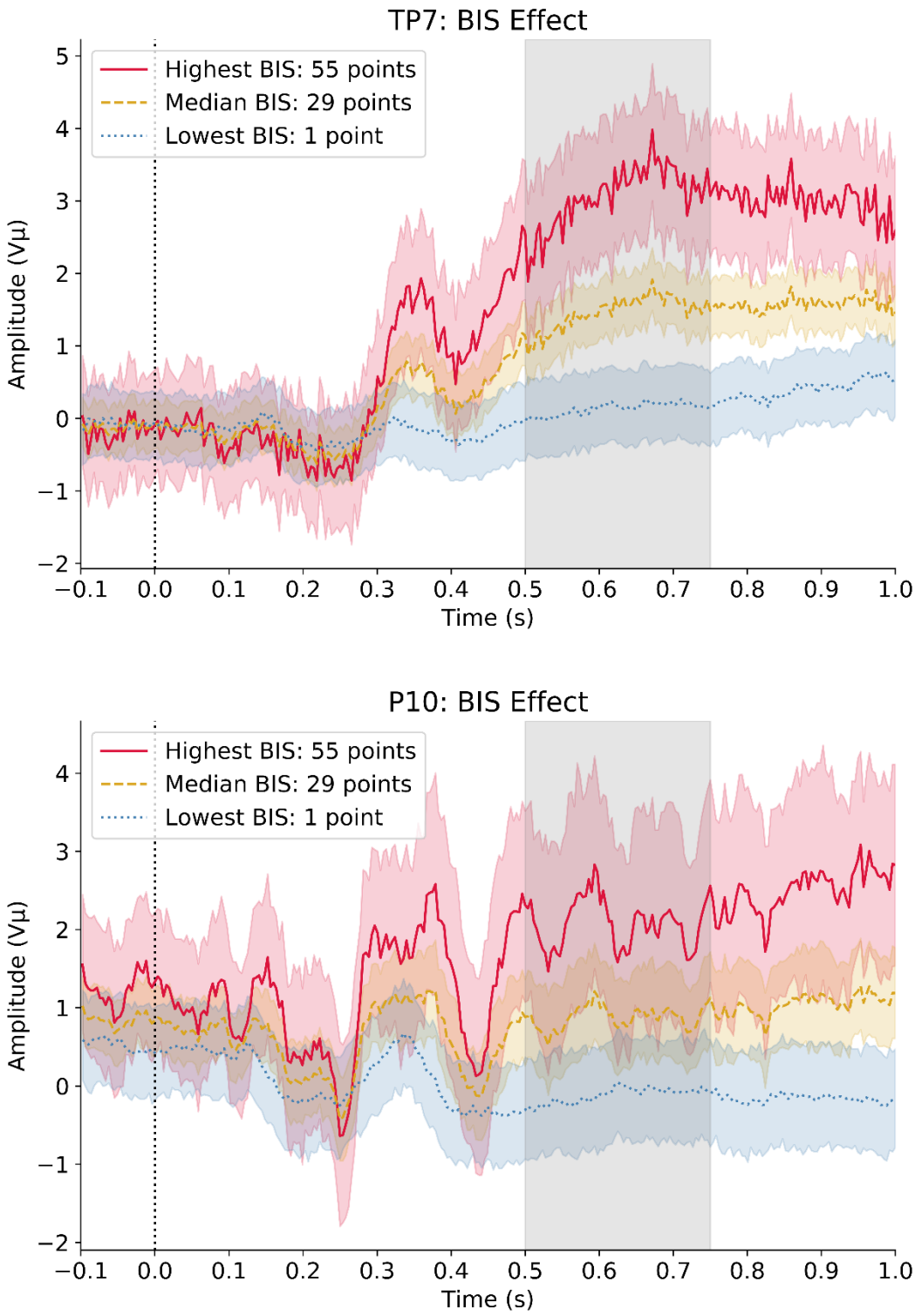

Figure 5. Images show amplitude waves from a regression across 282 (26 baseline + 256 epoch) samples. Each estimated sample is a whole posterior distribution, shadows indicate 90% HDIs at each sample. Dotted lines in blue: lowest BIS (1 point). Dashed lines in yellow: sample's median BIS (29 points). Solid line in red: highest BIS (55 points). Note that higher levels of BIS tend to be noisier (such as containing more energy/faster frequency), and that effects at right hemisphere (TP7) reach greater positive amplitudes and have fewer overlapping HDIs. Vertical dotted line at zero: sentence onset.

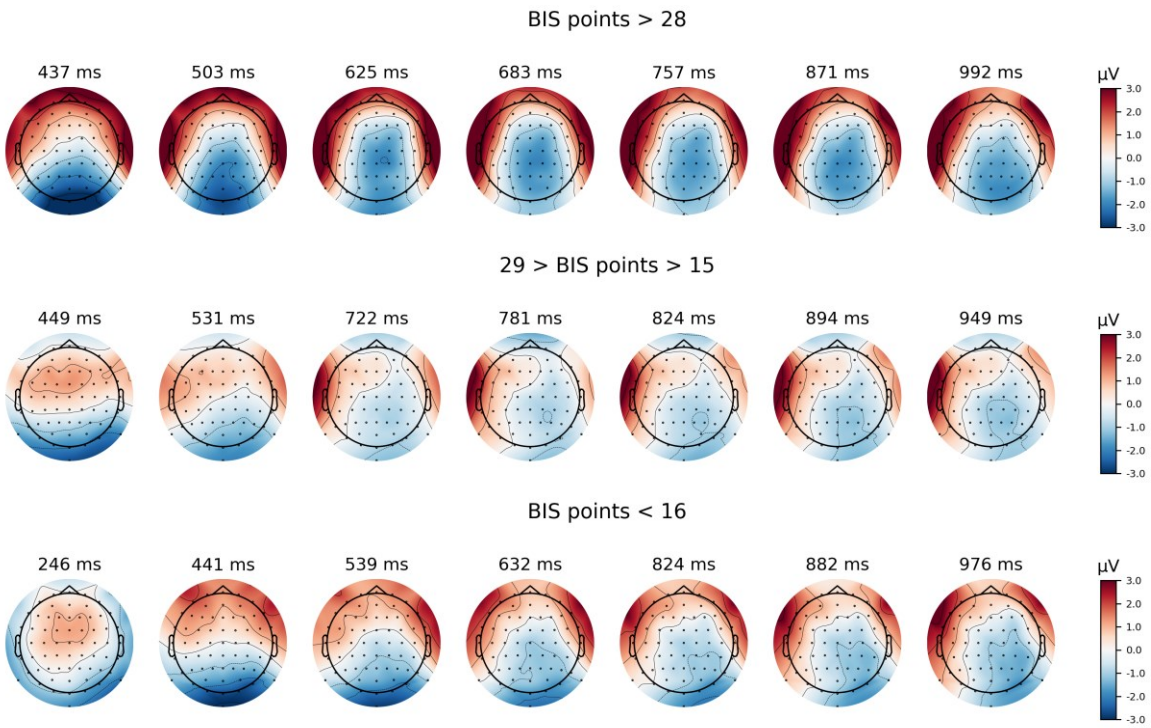

Figure 6. Images show raw mean amplitude across epoch by BIS tertile. Top: upper BIS score tertile. Middle: mid BIS score tertile. Bottom: lower BIS score tertile. Time-points were selected as the local maxim Global Field Power (GFP).

Figure 6 shows mean amplitude peaks selected by maximum local global field power (GFP). GFP indicates a spatial standard deviation quantifying electrical activity from all electrodes at specific time-points (Skrandies, 1990), reliably revealing peaks of greater amplitude. These peaks suggest the lack of earlier phases effects by BIS, only indicating sufficiently strong amplitudes from over 200ms for lower BIS levels (below 16 points) and from over 400ms for higher BIS levels (over 15 points). Our main analyses indicate that this might be due to very small effects in window1 (50-150ms), with no estimates over |0.5|µV for central electrodes (pooled by channel). These values progressively increase to up to around |1|µV and |2|µV for window2 (100-250ms) and window3 (250-500ms) respectively. Nevertheless, estimates by conditions (BIS, ear and type) indicate negligible increases, with amplitude consistently remaining around zero values. This can be seen in Figure 7, which summarises intercepts and slopes posterior distributions from the direct-threat task. We selected only the condition of BIS by Congruent at left ear for brevity, as all conditions evidenced similar patterns. Effects start to be noticed from window3 (250-500ms) and become considerable at window4 (500-750ms), indicating a bilateral temporo-parietal increase of ~0.05µV per BIS score point; consistent with Figure 5, where an increase of around 3µV can be observed from the lowest BIS score (1 point) to the highest BIS score (55 points).

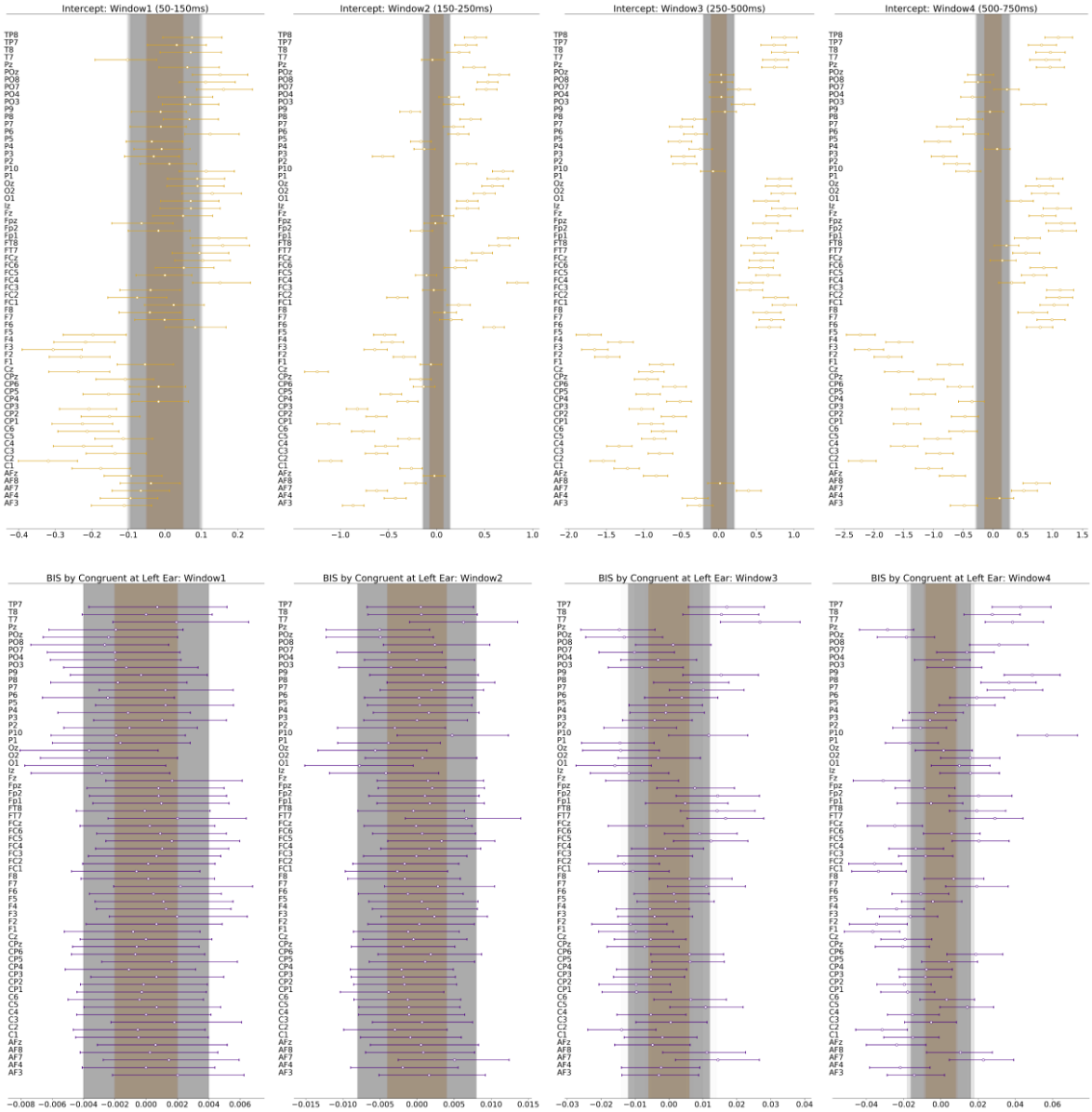

Figure 7. Figure contains forest plots summarising direct-threat results from a robust regression on mean amplitudes. Up: intercepts from all time-windows, which indicate pooled activity (non-varying) across 64 electrodes. Bottom: varying slopes estimates, from four time-windows, showing only one of the conditions (BIS by Congruent at Left Ear). Note that effects of BIS are only sufficiently strong the fourth time window, bilaterally, but particularly clear at left temporal and parietal electrodes such as T7, TP7, P7, P9.

These results suggest general effects of threatening language, but also indicate that BIS highly modulates amplitude effects, in particular at late time-windows. Table 5 gives a more thorough summary across all conditions for electrode TP7. We emphasise that the same pattern was observed in all electrodes showing strong amplitude increases. Whereas left-side temporo-parietal electrodes increase from near zero values (e.g. T7, TP7, P7, P7), right-side electrodes show increases from negative amplitudes (e.g. TP8, P10) and less clear LPC. Figure 7 shows regression lines for TP7 across all conditions.

Table 8. Estimates from TP7 across all conditions for lowest and highest BIS scores

Channel	Type	Ear	BIS score	Mean	SD	HDI 5%	HDI 95%	ESS (bulk)	$\widehat{R}$
TP7	Prosody	left	1	0.05	0.01	0.04	0.06	2273.18	1.00
TP7	Semantic	left	1	0.05	0.01	0.04	0.06	2138.45	1.00
TP7	Congruent	left	1	0.04	0.01	0.03	0.06	2161.74	1.00
TP7	Prosody	right	1	0.05	0.01	0.03	0.06	2140.95	1.00
TP7	Semantic	right	1	0.06	0.01	0.04	0.07	2168.43	1.00
TP7	Congruent	right	1	0.04	0.01	0.03	0.06	2314.09	1.00
TP7	Prosody	left	55	2.77	0.45	2.04	3.51	2273.18	1.00
TP7	Semantic	left	55	2.82	0.46	2.09	3.57	2138.45	1.00
TP7	Congruent	left	55	2.36	0.46	1.64	3.14	2161.74	1.00
TP7	Prosody	right	55	2.67	0.46	1.88	3.39	2140.95	1.00
TP7	Semantic	right	55	3.04	0.47	2.29	3.82	2168.43	1.00
TP7	Congruent	right	55	2.47	0.48	1.65	3.22	2314.09	1.00

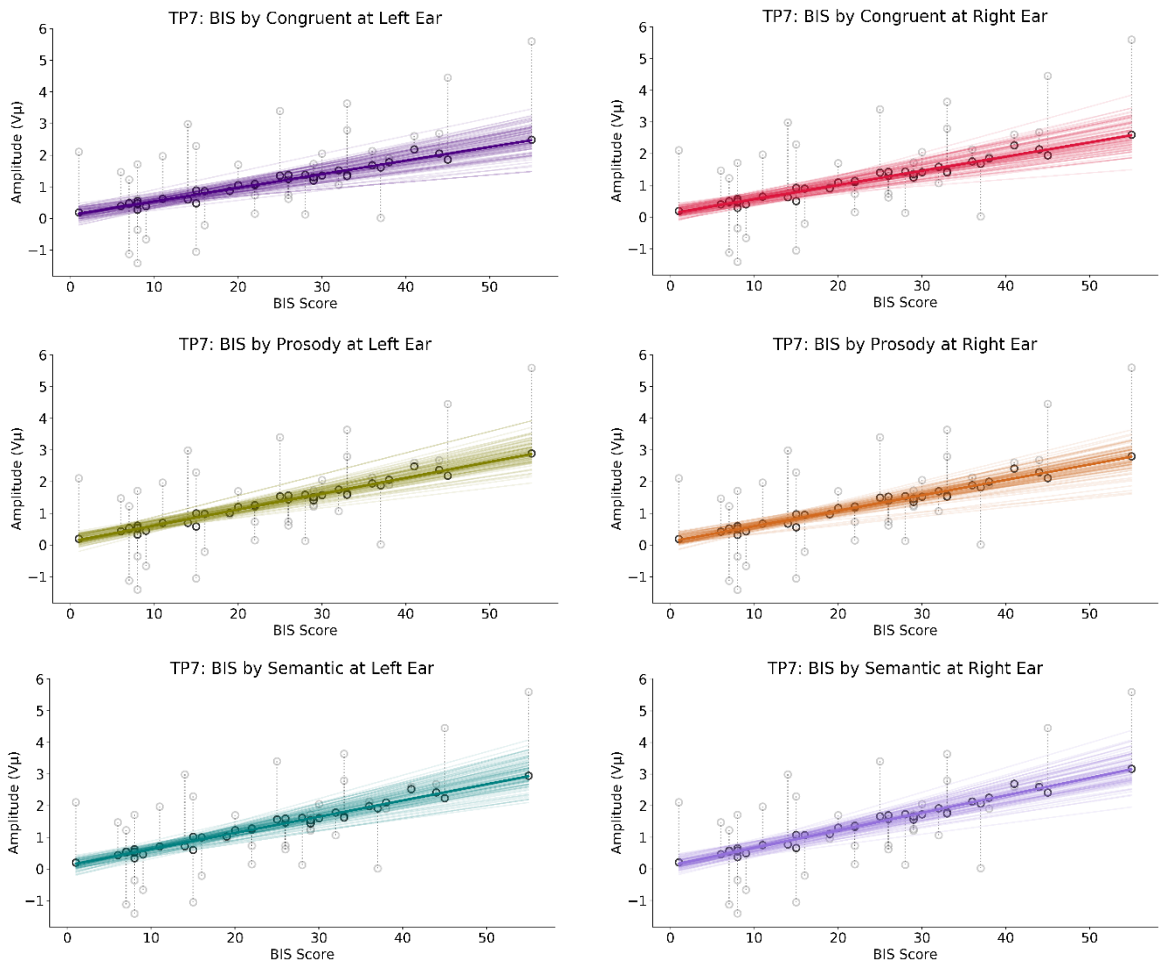

Figure 7. Images show regression lines for TP7 electrode, each point in the line is a posterior distribution, faded lines are random samples from the posterior expressing uncertainty. Grey circles indicate raw mean amplitude per participant. Black circles indicate estimated mean amplitude per participants. Dotted lines indicate shrinkage.

Exploratory Results

Finally, we conducted two exploratory analyses. Firstly, we analysed amplitudes from epochs aligned with response execution. It has been suggested that this method is crucial for observing response preparation P600 ERPs (Sassenhagen et al., 2014; Sassenhagen and Bornkessel-Schlesewsky, 2015). Given this, we wanted to assure that the LPC we observed reflects a deliberation phase and not response preparation. Thus, we locked each epoch's offset to each trial's RT and defined epoch's onset as 1s previous to RT with a 200ms baseline. Our prediction was to find a P600 similar to the one observed in previous literature, which would corroborate that the observed LPC appearing ~600ms after sentence's onset is a different ERP that the P600 appearing when epochs are RT locked. Analyses were performed exactly as for the main models, but with mean amplitudes from a 600-800ms time-window. Both direct- and

indirect-threat conditions indicate strong amplitude increases. This confirms a response-aligned P600 which is different from the observed LPC, as average RT (555.21ms) and average sentence duration (1646.30ms) guarantee that responses will generally not overlap or the LPC would be captured by the baseline. Indirect-threat did not show any differences as modulated by stimulus type, ear presentation or BIS score. However, contrary to our expectations, direct-threat indicated small increases for Prosody at the left ear as BIS score increased (~0.025µV per BIS point) at few frontal electrodes, while Semantic at the right ear showed similar but more consistent increases at posterior electrodes (e.g. Oz, O2). Although very small, these effects might be associated with earlier BIS effects, which could be accumulated until near response execution. Figure 8 summarises these results for the Semantic/right-ear condition by using electrode Oz as example. See our OSF repository for all summaries and plots.

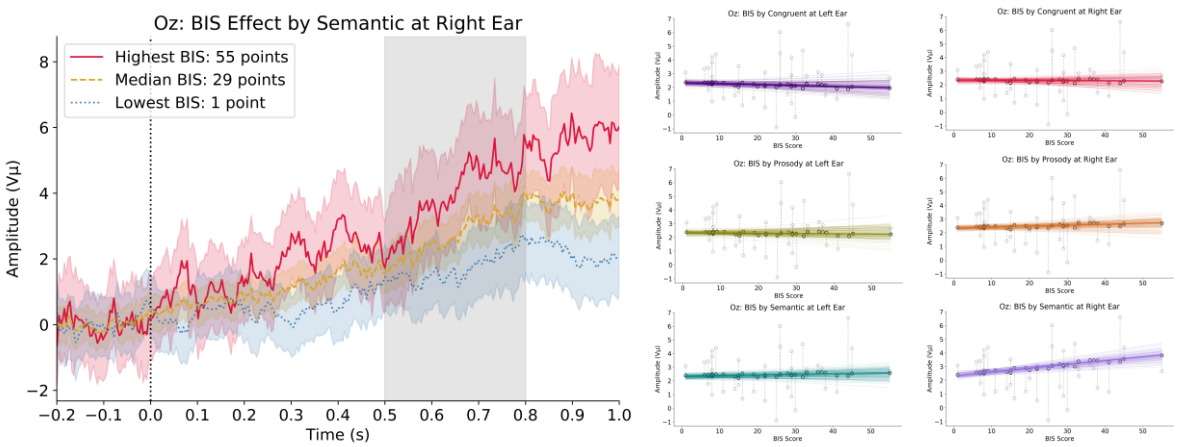

Figure 8. Image at the left shows regressed amplitude waves from electrode Oz, shadows indicate HDIs. Note that there is barely or no overlap between highest and lowest BIS sores at later times in the epoch. Images at right show regression lines containing posteriors from all conditions, faded lines express uncertainty. Note Semantic at right ear (bottom right), whose uncertainty does not overlap with other conditions at higher BIS scores. Vertical grey dotted line: RT-locked onset.

The second exploratory analysis consists of source-localising amplitudes from window4. Our aim is to identify potential activity sources for the observed LPC. According to emotional acoustic and language processing (Früholz et al., 2016; Kotz and Paulmann, 2011) and anxiety models (Robinson et al., 2019), most probable sources of activity should be in areas of emotional and language processing. On average across the 500-800ms window, we expected to observe increases of left-temporal activity in association with basal ganglia (emotional language processing) and amygdala-hippocampal activity in association with right prefrontal activity (anxiety processing). Based on this, we performed exploratory source localization analyses over the 500-800ms time window from each sentence's onset. For

simplicity, we averaged estimated activity across the temporal dimension, and tested whether activity at given voxel and/or anatomical areas increased as a function of BIS.

Table 9. Highest log-activation estimates from Voxel by BIS interaction.

Brodmann Area	Activation	MNI x	MNI y	MNI z	Mean	SD	HDI 5%	HDI 95%
Left-BA21	0.487	-50	-50	10	0.020	0.007	0.008	0.031
Left-Caudate (48)	0.199	-10	25	10	0.019	0.007	0.008	0.031
Left-BA22	0.508	-50	-45	15	0.018	0.007	0.007	0.030
Left-Insula (13)	0.218	-20	25	15	0.016	0.007	0.004	0.028
Right-Caudate (48)	0.228	5	25	5	0.016	0.007	0.004	0.028
Left-BA45	0.214	-20	30	15	0.016	0.007	0.003	0.027
Left-PrimAuditory (41)	0.564	-45	-35	10	0.015	0.007	0.003	0.026
Left-BA9	0.207	-20	25	20	0.014	0.007	0.003	0.026
Right-BA9	0.115	10	35	20	0.014	0.007	0.002	0.025
Left-BA10	0.278	-20	35	10	0.013	0.007	0.002	0.025
Left-BA8	0.229	-20	20	25	0.013	0.007	0.001	0.024

Note: Coordinates are in the Montreal Institute of Technology (MNI) system. Activation is the raw mean in log scale.

Epochs from the direct-threat condition were sourced localized with exact low resolution brain electromagnetic tomography (eLORETA) (Pascual-Marqui et al., 2018), using standard values in the Pyhton package MNE (Gramfort et al., 2013), involving 14629 voxels with a minimal distance of sources from skull of 5mm; coordinates in the Montreat Institute of Technolgy atlas (MNI). Due to lack of participants' anatomical images, a Free Surfer average brain was used. The computed sources from the whole epoch, per participant (36) were averaged in the 500-800ms time-window over the time dimension, and extracted as images in NIFTI format. Data and plots from these images were handled using Python packages Nibabel and Nilearn (see: Abraham et al., 2014). For simplicity and to more easily achieve convergence, resulting estimated activation was analysed via Bayesian regression, simply using normal fixed priors and a normal distribution for log-transformed activation. Two analyses were conducted, one containing an interaction between 4877 voxels extracted from 38 regions of interest (ROIs) and BIS scores; the 38 ROIs were selected as the main areas composing emotional language and anxiety processing (see: Kotz and Paulmann, 2011; Robinson et al., 2019). The second contained an interaction between the total 116 observed anatomical areas and BIS score, so we could attest for pooled activity across areas that might have been missed by the first model.

Table 5 summarises results from effects in voxels showing HDIs over zero, showing peaks at cytoarchitecnotic Brodmann areas (BA). Note that they do not go over 2SD ROPEs, and few go over 1SD ROPEs.

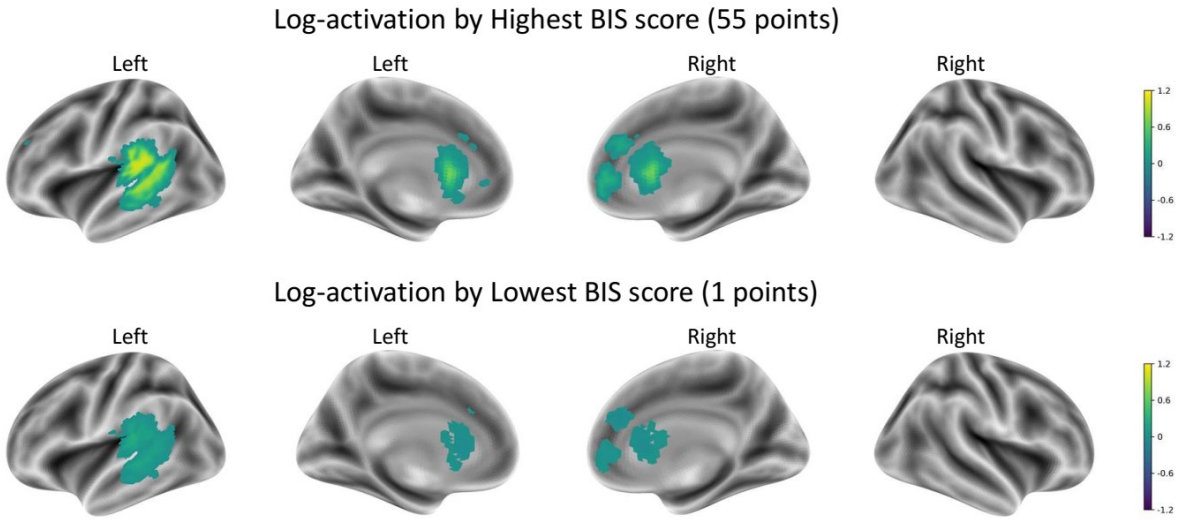

Figure 8. Images show estimated log-activation at the lowest BIS (bottom) and highest BIS (top) levels, plotted over inflated brain surfaces. The strongest increase from lowest to highest BIS happens at left superior temporal cortex (STC) and mid temporal cortex (MTC), followed by caudate nucleus (CN) and later by middle prefrontal cortex (mPFC) at very ventral and interior parts.

Voxel-based results confirm activity in left auditory cortex and temporal language-associated cortex, the greatest increases is 1.08 log-activation a.u. from lowest BIS (0.02 a.u.) to highest BIS (1.1 a.u.) score. In addition, bilateral mPFC, and bilateral caudate nucleus (CN) was observed. This goes in line with predictions of prefrontal, temporal and basal ganglia involvement, but they do not show amygdala or hippocampal activity (See Figure 8). Although, given that we expect imprecision from source localization using average anatomies, some portions of CN might be overlapping with hippocampus and/or amygdala. The second analysis, summarized in Figure 9, shows that when pooling across anatomical region estimates indicate strong increases of activity (~0.01 log-activation a.u. by BIS point) in areas such as mPFC, CN, hippocampus and amygdala, but also in portions of entorhinal cortex, which connects with temporal cortex. Indeed, some of the greatest increases as a function of BIS occur in the temporal pole, MTC and STC, extending to supramarginal gyrus (SMG). In addition, these analyses also indicate that activity in visual and motor areas tends to decrease as a function of BIS. This is in line with participants withholding responses during LPC activity, as response preparation will come later, signaled by a response-locked P600. Although these results are exploratory and would require further support from MEG and/or fMRI analyses, they are in

line with emotional language processing and anxiety operating in tandem as predicted by current models.

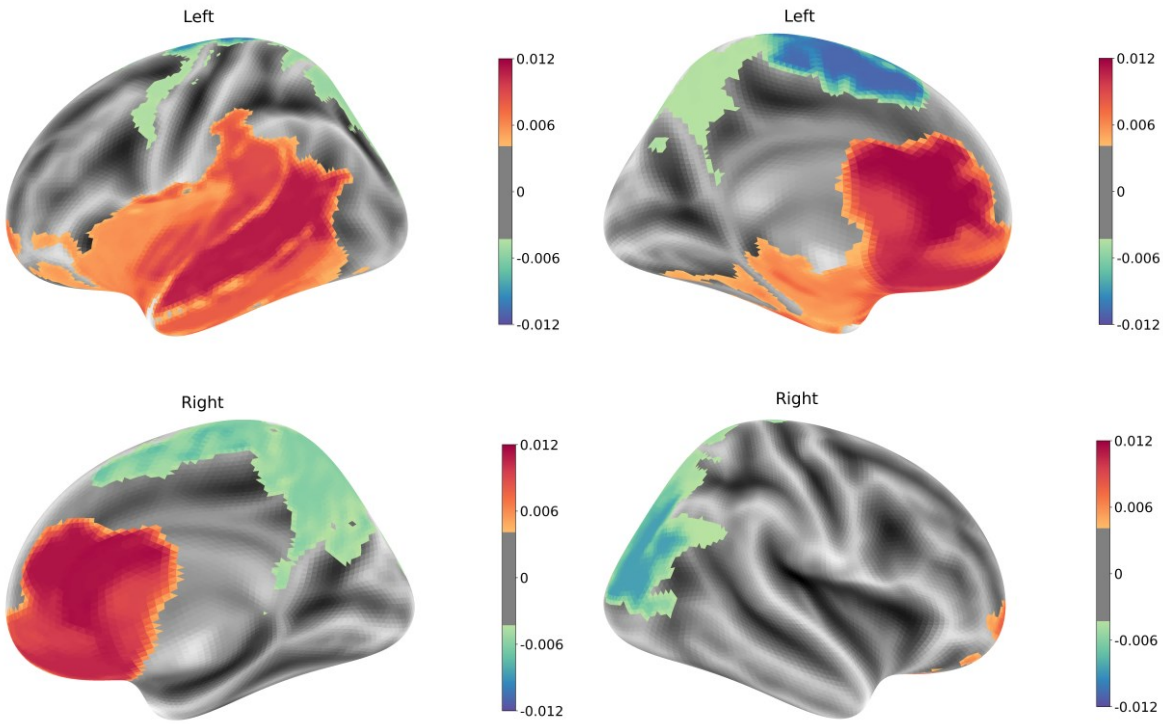

Figure 9. Images show estimated log-activation slope estimates from the model using a BIS by Anatomical Area interaction. Threshold is placed at the biggest 2SD ROPE from all estimates (0.0042). Note that maximal increases occur at bilateral basal ganglia and left temporal cortex, followed by left amygdala, hippocampus, entorhinal cortex and insula and parts of right prefrontal cortex; while maximal decreases can be seen at left motor cortex, followed by parts of bilateral parietal and right occipital cortex. Scales are in arbitrary units (a.u.).

Discussion

Present results indicate that threatening stimuli in both direct- and indirect-threat tasks induce longer RTs as a function of BIS (trait anxiety), but have no effects on accuracy, which only shows differences when selecting slopes by ear or type, indicating conventional dichotic listening effects (see our OSF repository: https://osf.io/n5b6h/?view_only=358e8b2d52684c92ac63aded03b22325). These results replicate previous behavioral findings very closely (Busch-Moreno et al., 2020), consistent with the interpretation of trait anxiety disrupting deliberation/orientation, as accuracy is minorly affected but RTs are strongly affected by trait anxiety levels. EEG results indicate that an LPC increases its amplitude as a function of BIS, also consistent with our hypothesis indicating late phase effects of trait anxiety on threatening language processing during

orientative/deliberation phases. However, no earlier effects can be observed as a function of BIS, which goes contrary to our hypotheses predicting the influence of trait anxiety at all time-windows from sentence onset.

ERP exploratory analyses indicate that when epochs are locked to RT, a P600 signals response preparation. This result rules out the observed LPC as a P600-like ERP, supporting instead its relationship with trait anxiety. In addition, the response-locked P600 is modulated by BIS, showing small type by ear effects. Finally, a source localization exploratory analysis indicates that possible sources for the LPC are direct matches with areas involved with emotional language and anxiety processing, as predicted by the current implemented models, but not closely matching our particular prediction. Instead of observing stronger RH activity at the ~600ms time-window, main analyses indicate stronger and clearer LH activity, and the exploratory source localization shows that this activity might come from left temporal cortex. Overall, results and exploratory results support the idea of trait anxiety influencing late phase processing (over 500ms), which is associated with response slowdown possibly derived from effects of verbal repetitive thinking during a pre-response deliberation phase.

Although some EEG studies show lateralization effects associated with emotional semantic and prosody variation (Kotz and Paulmann, 2007), recent research does not show much evidence for these effects (Chen et al., 2011; Paulmann et al., 2012). One proposed explanation is that concurrent multi-channel (prosody and semantic) information obscures laterality effects (Paulmann et al., 2012). Present results are consistent with this interpretation, in particular when considering that when pooling amplitude by electrode the ERP pattern shows canonical ERP responses to emotional language at earlier time-windows (e.g. N2, N400). Most importantly, effects of anxiety at later time-windows in the form of an LPC are not modulated by stimulus type (semantic or prosody). This differs from previous research, which did not include anxiety measures, finding late positive amplitudes in association with prosody/semantic emotional variations and/or congruency effects (Astésano et al., 2004; Chen et al., 2011; Zhao et al., 2015). Hence, the present LPC can be understood as signaling a general anxious response to threatening language.

However, previous EEG research studying the effects of visually presented (written) abusive words on non-anxious people (Wabnitz et al., 2012) shows much earlier effects, modulating P100 (~100ms) and N400 (~400ms) amplitudes, both ERPs showed greater deflections for threatening words. When a similar procedure included socially anxious subjects (Wabnitz et al., 2015), results indicated a decreased P100 and an unaffected N400 for socially anxious people. Differently, present results indicate very weak evidence for anxiety effects at

early time-windows. This aligns better with a study testing the effects of emotional syllables and vocalization, which found that trait anxiety is associated with a lower LPC when participants listened to emotional speech (Pell et al., 2015). This pattern, however, is the opposite to what we observed, though both LPCs share very similar latencies and scalp distributions. One possible explanation is that when answering to syllables, anxious participants resolve responses at much earlier time-windows, where larger components at an early-mid stage (~100-300ms), such as P2 or EPN, are observed (Pell et al., 2015; Wabnitz et al., 2015). Another possible and complementary explanation is that these prior experiments used probe tasks, thus emphasizing implicit responses, which elicited much clearer early-mid stage effects and behavioural responses that occurred before deliberation could take place.

This could imply that the present LPC requires the deliberation time provided by present stimuli, namely long duration sentences. Trait anxiety has been strongly associated with patterns of repetitive thinking (McEvoy, 2010; McLaughlin, 2007). This has been also proposed as an explanation for lateralisation patterns in higher worriers (Spielberg et al., 2013). It is possible that predispositions to worry and/or rumination, elicited by an overactive BIS, induce verbal repetitive thinking, in particular when stimuli are threatening language. In line with this interpretation, LPC has been understood as a marker of decision modulation in relation to evaluation through memory processes (Finningan et al., 2002; Yang et al., 2019). This LPC was elicited in response to judgements on words, and it was a left-lateral central-parietal positive deflection. This partially aligns with our observations, though some differences might be expected as we used a higher density setup with average reference. Nonetheless, we emphasise the role of BIS in our present observations. That is, the present LPC would not only be associated with response control, but also with that response control in terms of behavioural inhibition. This would imply that trait anxiety, expressing an overactive BIS, would involve over-engagement with threatening stimuli and induce verbal repetitive thinking. This would result in the involvement of left hemisphere, in particular of structures associated with auditory and language processing, understood as an inner speech phonological loop (Buchsbaum and D'Esposito, 2008; Vigliocco and Hartsuiker, 2002). Evidence from fMRI suggest that inner speech mainly involves areas such as inferior frontal gyrus (IFG), angular gyrus and SMG (Geva, 2018). Our exploratory source localisation analyses, differently, show weak IFG but strong left primary auditory cortex activity, MTC and STC extending to SMG. This might be associated with source localization capturing shorter time-frames as opposed to fMRI capturing longer processing, which might end up in the recruitment of articulatory areas. Also, this may respond to present inner speech, possibly associated with

verbal repetitive thinking, being focused more on imagery than rehearsal, thus deriving towards areas involved in phonological and semantic representation (e.g. BA21, BA41).

Interestingly, our exploratory analyses also show that increases in BIS are not only associated with increased left temporal activity, but also with decreased motor activity (mainly BA6). This could imply greater inhibition, not only explaining slower responses, but also supporting the notion that actual motor control happens later and in association with responses. It has been proposed that positive amplitude deflections, such as P300 and P600, are related with cortical re-orientation towards execution/inhibition of responses (Sassenhagen et al., 2014; Sassenhagen and Bornkessel-Schlesewsky, 2015). This proposal is based on the alignment of these ERPs with RTs (e.g. response preparation), as a marker of adrenergic secretion eliciting shifts between ventral and dorsal attention networks (Corbetta et al., 2008). These end up in frontoparietal areas where a right-lateralized ventral network orients attention to environment and inhibits a goal-oriented dorsal network. This is consistent with both of our exploratory analyses, as we observed a response-locked P600, and also an increase in mPFC in source localization of the sentence-onset-locked LPC. This area has been related with inhibitory control in relation with attention processes (Corbertta et al., 2008; Vuilleumier and Driver, 2007). Previous research suggest that BIS-related inhibitory control is linked to right hemisphere (RH) frontal cortex (Gable et al., 2018), in particular when tasks require refraining responses (Neo et al., 2011; McNaughton et al., 2013).

Nevertheless, when tasks are associated with rumination or worry, a strong RH pattern is not usually present (De Pascalis et al., 2013; Keune et al., 2012). This might indicate an interplay between right and left hemispheres, where the latter works as an inhibitor of action (either approach or withdrawal) and the former as an inhibitor of ongoing deliberation. In other words, when responses need to be refrained from or suppressed, the ongoing required behaviour is response-withdrawal. Right-handed anxious participants might find difficult to refrain from responses due to left hemisphere interference (left-lateralized movement control). Similarly, if the task induces language-related repetitive thinking, LH might interfere through rumination or worry, thus RH would need to inhibit that ongoing activity to permit responses. As our task did not involve a go-no-go paradigm, but all responses needed to be delayed, the additional inhibition time may have allowed for the interaction between behaviour control and evaluation mechanisms, effectively involving left hemisphere temporal structures, limbic system and prefrontal structures. This might imply that more networks could be involved, in particular those associated with behavioural inhibition as mediated by serotoninergic control through raphe nucleus and amygdala-hippocampal routes (Andrade et al., 2013). And, also

those involving language areas and basal ganglia, the latter playing a role in verbal emotional language processing (Paulmann et al., 2009; Pell and Leonard, 2003). To note, our exploratory analysis also showed strong activity in basal ganglia, in particular CN, accompanied by smaller degrees of amygdala, hippocampal and entorhinal activity. Hence, there could be an interplay between these systems, where attention control is also mediated by BIS in terms of learning and memory. For instance, by comparing current environment conditions with past experience; consistent with notions of worry and rumination as post-event processing repetitive thinking (McEvoy et al., 2010). Therefore, increased left hemisphere activity elicited by repetitive thinking related processes such as internal dialogue and categorization remains plausible.

Under this notion, inhibition processes need to be transferred from right to left hemisphere, which would induce faster recession of right hemisphere activity, longer and stronger latency of left hemisphere activity, and different scalp distributions at each hemisphere. Although this is a parsimonious explanation when theories of callosal relay are taken into account (Friederici et al., 2007; Grimshaw et al., 2003; Steinmann et al., 2017; Westernhausen and Hugdahl, 2008), it becomes difficult to explain why there are not earlier ear or type differences in association with hemisphericity patterns. One possible explanation is the horse-race model of callosal transferring (Grimshaw et al., 2003), which indicates that ear of presentation would privilege the contralateral hemisphere not as an immediate effect, but in long run. This would be the effect of the delay caused by callosal transferring. Indeed, our main analyses, using epochs locked to sentence onset, do not show amplitude differences of this sort. However, when epochs are locked to RT, these differences (though small) become evident, in particular for Semantic stimuli at right ear and with slight central-left posterior pattern (e.g. Oz, O2). Nonetheless, due to BIS effects, instead of creating an advantage, responses become slower. This would emphasise that even processing is privileged, it is more effortful for people with higher trait anxiety due to the threatening nature of the stimuli; which is in line with our main analyses.

Overall, contrary to previous observations (Pell et al., 2015), our main results show an LPC increase as a function of BIS; strongly indicating that our proposed expanded model of emotional language processing is plausible. Observations indicate that core features of auditory and emotional language processing (Kotz and Paulmann, 2011; Früholz et al., 2016) are present, but can drastically vary when taking individual differences into account (i.e. trait anxiety). In anatomical terms, emotional auditory processing models (Früholz et al., 2016) are strongly consistent with current models of anxiety processing (Robinson et al., 2019). However, the latter do not directly include the time domain as processing phases. We have

proposed this inclusion in terms of anxious attention (Bar-Haim et al., 2007) and attention models (e.g. Corbetta et al., 2008). Current results indicate that this inclusion is viable as a fourth phase of a model emotional language processing (Kotz and Paulmann, 2011), where deliberation mechanisms can play a role. This would imply phases: 1) Perception (~100ms), 2) Recognition (~200ms), 3) Evaluation (~400ms), 4) Deliberation (~600ms). Although we have discussed response preparation in terms of exploratory analyses, currently we have no evidence or theoretical rationale to propose the integration of this process as a phase of emotional language processing, as it could respond to more general mechanisms. Thus, it could be argued that the present observed effects of BIS could also correspond to a more general process. We agree, but also remark that this broader mechanism has particular effects on threatening language processing due to the tight relationship between anxious features (i.e. worry/rumination induced verbal repetitive thinking) and language processing features (i.e. phonological loop), plus the relationship between the affective and cognitive processing required for both and anxiety and language.

Finally, we want to refer to some relevant limitations of our study. Firstly, an obvious caveat is that there is no direct neutral control. Even though we used an indirect-threat task, this is usually intended to control for attentional differences (e.g. Sander et al., 2005; Peschard et al., 2016). Although the experimental requirements of the present task design do not allow for having a response to Neutral stimuli without threat interference, future research could address neutral vs threat more direct differences by, for example, between-groups designs. Secondly, although we identify patterns of right hemisphere activity associated with anxiety, in addition to left hemisphere patterns, it is important to address experimental designs that directly induce response inhibition to differentiated stimuli. Previous research has indeed proposed that tasks such as go-no-go are ideal for understanding BIS processes (e.g. McNaughton et al., 2013; Neo et al., 2011). Future research could include such tasks by, for instance, including responses to stimuli type instead to general threat. In association with this, spotting effective hemisphericity differences requires support of more precise anatomical measurements. Although previous fMRI studies (e.g. Sander et al., 2005; Spielberg et al., 2013) partially match with our proposed extended model, they do not include tasks equivalent to ours, so differences can be expected. This implies that fMRI or MEG research, or at least more precise source localization (i.e. using individual anatomies) are required for expanding present results and rounding the extended model on the anatomical side. Last but least, the possible influence of verbal repetitive thinking needs to be directly tested, with tasks specifically

designed to do so (e.g. Nalborczyk et al., 2017). Thus, experimental design using methods such as language interference could be relevant to address whether anxiety induced verbal repetitive thinking has particular effects on threatening language or it is unrelated.

In conclusion, present experimental results replicate previous behavioural results and provide strong evidence for trait anxiety effects. ERP analyses show that these responses are preceded by a clear positive amplitude deflection in temporal electrodes. We interpreted this event as an LPC, and associated it with trait anxiety affecting deliberation processes through verbal repetitive thinking. As BIS scores increased, the LPC became more positive, suggesting a disruptive deliberation process, such as induced by over-engagement with threat, during an orientative stage. In other words, higher levels of anxiety due to their association with repetitive thinking (i.e. worry and rumination) induce a more effortful decision-making process after evaluation of threatening stimuli. Although this represents strong support for part of our hypothesis, several limitations were discussed, and need to be addressed. The development of more sensitive tasks and alternative statistical models and approaches would help to understand earlier processes underpinning the proposed deliberation stage. In addition, the observed relationship between anxiety and language is not specific to speech information type. Hence, the effects of anxiety on prosody and semantics remain to be further explored. Overall, this experiment paves the way for future research on the relationship between speech, individual differences and emotional language in terms of information channels, anxiety and threatening language. This outlines an improved basis for reshaping models of emotional language processing by providing clear evidence on how anxiety can affect late processing phases.

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Declaration of interests

None.

Data statement

All data, analyses' scripts, and additional info can be found at the Open Science Framework (OSF) repository: (will be provided after review process)
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