**Running head: TRAIT SUSCEPTIBILITY TO WORRY**

# Trait susceptibility to worry modulates the effects of cognitive load on cognitive control: An ERP study

*Max Owens, Nazanin Derakshan, and Anne Richards*

*Department of Psychological Sciences, Birkbeck University of London, UK*

**Word count: (including abstract) 2508**

Author Notes

This work was supported by a British Academy grant (SG112866) awarded to Nazanin Derakshan and Anne Richards. Max Owens is now at Binghamton University State University of New York, USA. Nazanin Derakshan is a Visiting Professor at the Department of Experimental Psychology, University of Oxford.

Correspondence to: Professors Nazanin Derakhshan (n.derakhshan@bbk.ac.uk) or Anne Richards (a.richards@bbk.ac.uk).

## Abstract

According to the predictions of Attentional Control Theory of Anxiety (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007) worry is a central feature of anxiety that interferes with the ability to inhibit distracting information necessary for successful task performance. However, it is unclear how such cognitive control deficits are modulated by task demands and by the emotionality of the distractors. A sample of 31 participants (25 female) completed a novel flanker task with emotional and neutral distractors under low and high cognitive load conditions. The negative going N2 event-related potential was measured to index participants' level of top-down resource allocation in the inhibition of distractors under high and low load conditions. Results showed N2 amplitudes were larger under high compared to low load conditions. In addition, under high but not low load, trait worry was associated with greater N2 amplitudes. Our findings support ACT predictions that trait worry adversely affects goal-directed behaviour and is associated with greater recruitment of cognitive resources to inhibit the impact of distracting information under conditions where cognitive resources are taxed.


Key words: Anxiety, Worry, Flanker, Cognitive Load, Cognitive Control, ERPs, N2

**Trait susceptibility to worry modulates the effects of cognitive load on cognitive control: an ERP study**

Chronic, excessive and uncontrollable worry is considered to be a central feature of anxiety (Diagnostic and Statistical Manual of Mental Disorders 4th Edition: DSM IV; American Psychological Association, 1994). As described by the Attentional Control Theory (ACT) of anxiety (Eysenck, Derakshan, Santos, & Calvo, 2007) worry contributes to cognitive dysfunction by increasing cognitive interference and occupying attentional resources of the limited capacity working memory system that are needed for successful task performance. In this way worry is theorized to impair processing efficiency, where efficiency reflects the amount of effort needed to maintain effective task performance.

Processing efficiency impairments in anxiety have usually been accompanied by increased neural activation in prefrontal regions of control in the absence of modulations of behavioural performance in tasks where participants were required to exercise the inhibition function of working memory in accomplishing task goals (see Basten et al., 2011, 2012; Righi, Mcacci, & Viggiano, 2009; Sehlmeyer et al., 2010; see Berggren & Derakshan, 2013). In a modified non-emotional Go/No Go task, Righi et al. (2009) found that anxious individuals had similar behavioural performance to controls but displayed increased N2 frontal activity, typically associated with conflict processing and effortful control (Kanske & Kotz, 2012).

In line with predictions from ACT; high- compared to low-trait anxious individuals often show increased interference from irrelevant threat information on emotional Stroop and dot-probe paradigms (Richards & Blanchette, 2004, see Bar-Haim et al. 2007, for a review), visual search (e.g., Derakshan & Koster, 2010), and antisaccade tasks (e.g., Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009, see Berggren & Derakshan, 2013, for a review). More recently, however, trait susceptibility to worry was associated with the inefficient filtering of irrelevant threat-related information from visual working memory (Stout, Shackman, & Larson, 2013, 2014), suggesting that high levels of worry help retain negative information in working memory and this contributes to poor processing efficiency. Sussman et al. (2013) found that negative stimuli impaired task-relevant processing compared with neutral and positive distractors, and this was magnified as worry, rather than trait anxiety, increased. However, recent work using a colour-singleton visual search task with neutral distractors, found that trait anxiety rather than worry per se underpinned the attentional control deficit (Moser et al., 2012).

Given that worry is a central mechanism by which attentional control is impaired, individual variation in trait worry and variation of concurrent task demands may moderate neural reactivity. However, evidence for the effect of worry on neural activation is limited and previous attempts to manipulate the effect of task demands on performance in the presence of distracting emotional stimuli have been inconsistent (Pessoa, Kastner, & Ungerleider, 2002). For instance, whereas some studies have reported increased interference in anxiety from threat under high cognitive load (Judah, Grant, Lechner, & Adam, 2013) others have found no specific relationship (Berggren et al., 2013).

In the current study, we used a novel flanker task with emotional and neutral faces as distractors. We examined if anxiety, and in particular trait susceptibility to worry, modulated the inhibition of the distractors in low and high working memory load conditions. Neural activation in response to distractors was measured using the negative going conflict N2 event-related potential believed to reflect functional activation of the anterior cingulate cortex (ACC) related to conflict monitoring processes and cognitive control of working memory

(Yeung, Botvinick, & Cohen, 2004; Cavanagh & Shackman 2006), where working memory is conceived as a limited capacity system that co-ordinates cognitive processes to regulate attention and guide goal-directed behaviour (Miller & Cohen, 2001).

We predicted that anxiety, and in particular trait worry, should increase the processing of irrelevant distractors, leading to a greater recruitment of cognitive resources to perform the task as reflected in greater N2 amplitudes under conditions of high compared to low working memory load.

## Methods

### Participants

A final sample of 31 participants (25 Females) with normal or corrected-to-normal vision (mean age = 23.25, range 18-43) were analysed (data from one participant was lost due to power failure). Before each session self-report measures of anxiety (State-Trait Anxiety Inventory, STAI; Speilberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) and trait worry (The Worry Domains Questionnaire, WDQ; Tallis, Eysenck & Mathew, 1992; The Penn State Worry Questionnaire, PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) were completed. Scores for the state and trait anxiety questionnaires each ranged from 20 to 40. The WDQ comprises 25 items on worries across different domains (i.e. Relationships, Confidence, Future, Work and Financial), and scores ranged between 0 and 140. In contrast the PSWQ measures a general tendency towards worry independent of specific content of the worrying thoughts. The PSWQ consists of 16 items with scores ranging from 16 to 80. The WDQ and PSWQ are highly correlated; however items on the WDQ are believed to measure task-orientated problem-solving strategies (Davey, 1993). Each worry measure shows good internal consistency and retest reliability (Molina & Borkovec, 1994; Stöber, 1998; Van Rijsoort, Emmelkamp, & Vervaeke, 1999).

**Materials and Procedure**

The experiment was programmed using DMDX software (Forster & Forster, 2003) on a Dell Opitplex GX520 with a 17inch LCD (refresh rate: 60 Hz). We used a modified version of Erikson Flanker task (Erikson & Erikson, 1974) in which the central target was either a neutral male or female face, flanked by two distractor faces of the opposite gender on either side (see Figure 1). Distractor faces were angry, happy or neutral. Participants decided if the central target face was male or female by pressing one of two buttons. Forty-eight angry, happy and neutral male and female faces, divided equally between gender and emotional expression were chosen from the Karolinska Directed Emotional Faces set (Lundqvist & Ohman, 2005). Using MATLAB, faces were trimmed of all non-facial features, converted to 8-bit grayscale, and matched for luminance and contrast.

------Insert Figure 1 here-------

Cognitive load was manipulated by presenting an auditory tone of high, medium or low pitch played simultaneously with the faces (cf. Berggren et al., 2013). Within every trial participants heard a tone, with the only difference between conditions being the instructions given. For high load participants were instructed to remember the pitch of the tone and then verbally report after presentation of the faces whether the tone was “high”, “mid”, or “low”. In the low load condition participants were merely prompted to say ‘tone’. During the task participants verbal responses were monitored by microphone to ensure the task was performed adequately. There were five blocks of low and five blocks of high load trials presented separately each containing 96 trials, with block order counterbalanced across participants. Target faces (neutral male or female) and distractors (angry, happy, neutral) were randomized and presented equally within each block.

Each trial began with a central fixation for a randomly determined interval between 500 and 1000ms. The row of faces (target + distractors) and the tone were presented simultaneously, with the faces remaining on the screen for 1000ms or until a response was made. A prompt screen for the tone response then appeared and remained for 1000ms. Each experimental session lasted about 150 min. Participants were debriefed and received course credit for their contribution.

**ERP recording.** Participants sat in an electrically isolated, soundproof room with dimmed lighting. EEG was recorded using 64 Ag/AgCl sintered ring electrodes mounted on a fitted cap (EASYCAP) according to the International 10/20 system. Horizontal eye-movements were recorded from two electrodes placed 1 cm to the left and right of the external canthi. Eye blinks were recorded from a single electrode placed below the left eye. Electrode impedances were below 10 kΩ during testing. EEG data were recorded referenced to the left mastoid, and re-referenced offline to the mean of the left and right mastoids (average mastoids). EEG recordings were amplified and filtered with a BrainAmp standard model amplifier (Gain: 1000) with a band-pass at 0.01–80 Hz and sampled at 250 Hz.

**EEG Processing.** Data was processed offline using the MATLAB extension EEGLAB (Delrome & Makeig, 2004) and with the ERPLAB plugin (Lopez-Calderon & Luck, 2010). The data were low-pass filtered at 30 Hz. Independent component analysis (ICA) was first conducted to identify stereotypical ocular, muscle, and noise components (Jung et al., 2001). Artifact detection and rejection was then conducted on epoched uncorrected data files. Trials with ocular artifacts at stimulus presentation (blinks or saccades) were removed from both behavioural and ICA corrected continuous data. No participant lost more than 30% of trials during artifact rejection so all were included in analyses ($M$ = 871, $SD$ = 81). The number of usable trials across participants was uncorrelated with anxiety and worry (all *p's* > *.1*).

**ERP analysis** ERP waveforms were time-locked to target presentation with a 100ms baseline. EEG activity for each distractor (angry, happy, neutral) by load (low, high) was averaged separately for the N2 (215-275ms) component. ERP data was averaged across 12 frontal electrode sites (Fp1, Fp2, F3, F4, Fz, FC1, FC2, FCz, F1, F2, FC3, FC4).

## Results

Reaction time and accuracy data (proportion of correct responses) were analysed in two separate ANOVAs with Load (low, high) and Distractor Type (angry, happy, neutral) as within-subject factors. Mean N2 amplitude were analysed using a two-way ANOVA with distractor type (angry, happy, neutral), load (low, high) as within-subject variables. The Greenhouse-Geisser correction was applied when appropriate.

### Behavioural Performance

Performance was more accurate in low ($M$ = .90, $SD$ = .08) relative to high load trials ($M$ = .80, $SD$ = .11), $F(1, 30) = 39.32$, $p < .001$, $\eta_p^2 = .57$. No other effects were significant, $p$s > .2. Level of anxiety (trait, state) and worry (WDQ, PSWQ) were not correlated with accuracy data, $ps > .1$. Responses were faster under low ($M$ = 688, $SD$ = 47) relative to high load ($M$ = 744, $SD$ = 37; $F(1,30) = 78.47$, $p < .001$, $\eta_p^2 = .72$). There were no other significant effects ($F$s <2.24). Level of anxiety (trait, state) and worry (WDQ, PSWQ) were not correlated with reaction time data, $p$s > .1.

### N2 Analysis

A main effect of load for was observed, $F(1, 30) = 4.05$, $p = .05$, $\eta_p^2 = .12$, with greater N2 amplitudes under high (M = -3.97, SD = 2.15) compared with low load (M = -3.33, SD = 2.58; see Figure 2a). There was no main effect of distractor type or interaction between load and distractor type $Fs$<1.

-------Insert Figure 2 here-------

Trait worry (WDQ) correlated with the N2 amplitude under high $r(31) = -.38$, $p = .04$, but not low, $r(31) = -.17$, $p = .35$, load, and these correlations were marginally significantly different, $t(28) =1.63$, $p=.055$, one-tailed. The cost of load (high load – low load) on the N2 amplitude was calculated. Load cost was correlated with WDQ scores such that higher levels of worry on the WDQ were associated with greater N2 amplitudes for load cost, $r(31) = -.34$, $p = .06$. Next, a linear regression was performed with WDQ, generalized trait worry (PSWQ) and trait anxiety (TA) entered simultaneously in the model, and N2 load cost as the dependent variable. The WDQ significantly predicted N2 load cost, $\beta = -.67$, $t(27) = -2.67$, $p = .01$, see Figure 2b. Conversely, PSWQ, $\beta = .30$, $t(27) = 1.21$, $p > .2$ and TA, $\beta = .19$, $t(27) = 1.21$, $p > .4$ alone did not affect N2 load cost suggesting a specific modulatory role for WDQ on N2 amplitudes across load. The relationship between load cost on the N2 and WDQ was then examined for each distractor type and found to be particularly pronounced for angry distractors ($r = -.34$, $p = .06$) rather than happy (r= -.27, $p = .14$) and neutral ($r = -.29$, $p = .11$) distractors suggesting that higher levels of trait worry were associated with marginally greater N2 amplitudes in the inhibition of angry distractors in high load conditions.

## Discussion

The main findings of the current study are two-fold. First, under high cognitive load greater N2 amplitudes were observed relative to low load trials suggesting that greater attentional control resources were needed to inhibit the effect of the distracting flankers. Second, trait susceptibility to worry, as measured by the WDQ, modulated the distracting effect of the flankers on the N2 amplitude. It appears that the worry component of anxiety as measured by the WDQ rather than trait anxiety or a more general measure of worry (i.e., the PSWQ) per se is driving this association. Specifically, greater levels of trait worry were associated with enhanced N2 amplitudes under high but not low cognitive load. Importantly, in the absence of a modulation of worry on behavioural performance, findings of increased N2 amplitudes, under high cognitive load, suggest that worry can lead to a compensatory mechanism that necessitates the greater use of cognitive resources towards accomplishing the task goal.

Our findings support Attentional Control Theory's (Eysenck et al., 2007) prediction that trait susceptibility to worry is related to adverse effects on performance and processing efficiency on tasks imposing substantial demands on the processing and storage capacity of working memory. The current results add to the growing literature that suggests worry interferes with the recruitment of working memory functions by reducing processing efficiency (Hirsch & Mathews, 2012). They also extend recent evidence that shows trait vulnerability to worry interferes with the efficient filtering of task irrelevant threat distractors from working memory (Stout et al., 2014). The WDQ is believed to measure aspects of worry linked to attempts at task-orientated problem-solving (e.g. Davey, 1993). Our findings suggest that although such attempts may preserve on-going behavioural performance, trait worry as measured by the WDQ may also increase cognitive interference and effort. In this view, maladaptive attempts to regulate attention in worry, as in the related construct of depressive rumination, may help fuel a cycle of cognitive dysfunction and negative biases (cf. Nolen-Hoeksema, Wisco, Lyumbrisky, 2007). There was only a trend for a specific effect of worry on the inhibition of threat related distractors in the current study, and clearly more work is needed. Future research should therefore elucidate the mechanisms by which threatening information interferes with the recruitment of cognitive processes of control under high task demands. In conclusion, the current study adds to the growing evidence that worry impairs processing efficiency through a compensatory mechanism that aims to protect availability of cognitive resources towards goal-directed behaviour.

References

Basten, U., Stelzel, C., & Fiebach, C. (2012). Trait anxiety and the neural efficiency of manipulation in working memory. *Cognitive, Affective, and Behavioral Neuroscience. 12,* 571-588.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M.J., & van IJzendoorn, M.H. (2007). Threat-related attentional bias in anxious and non-anxious individuals: A meta-analytic study. *Psychological Bulletin*, *133*, 1-24.

Berggren, N., & Derakshan, N. (2013). Attentional control deficits in trait anxiety: Why you see them and why you don't. *Biological Psychology*, *92*, 440-446.

Cisler, J. M. & Koster, E. H. W. (2010). Mechanisms of attentional bias towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review, 30,* 203-216.

Delorme, A. & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134,* 9–21.

Davey, G. C. (1993). A comparison of three worry questionnaires. *Behaviour research and therapy*, *31*, 51-56.

Derakshan, N., Ansari, T.L., Hansard, M., Shoker, L., & Eysenck, M.W. (2009). Anxiety, inhibition, efficiency, and effectiveness: An investigation using the antisaccade task. *Experimental Psychology*, *56*, 48-55.

Derakshan, N.  & Koster, E. H. W. (2010). Processing efficiency in anxiety: Evidence from eye-movements during visual search. *Behaviour Research and Therapy, 48,* 1180-1185.

Dong, G., Yang, L., & Shen, Y. (2009). The course of visual searching to a target in fixaed location: Electrophysiological evidence from an emotional flanker task. *Neuroscience Letters, 460*, 1-5.

Eriksen, B. A. & Eriksen, C. W. (1974). "Effects of noise letters upon identification of a target letter in a non- search task". *Perception and Psychophysics, 16*, 143–149.

Eysenck, M. W. & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion, 6,* 409–434.

Eysenck, M.W., Derakshan, N., Santos, R., & Calvo, M.G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*, 336-353.

Forster, K.I. & Forster, J.C. (2003). DMDX: a Windows Display Program with millisecond accuracy. *Behavior Research Methods, Instruments and Computers, 35,* 116–24.

Friedman, N. & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of Experimental Psychology-General, 133*, 101–35.

Hirsh, C., & Mathews, A. (2012). A cognitive model of pathological worry. *Behaviour Research and Therapy, 50,* 636-646.

Judah, M.R., Grant, D.M., Lechner, W.V., & Mills, A.C. (2013). Working memory load moderates late attentional bias in social anxiety. *Cognition and Emotion*, *27*, 502-511.

Kanske, P. & Kotz, S. A. (2012). Effortful control, depression, and anxiety correlate with the influence of emotion on executive attentional control. *Biological Psychology, 91,* 88-95.

Lopez-Calderon, J. & Luck, S.J. (2010). ERPLAB (version 1.0.0.33a) (Computer Software). UC-Davis Center for Mind & Brain. http://erpinfo.org/erplab/erplab-download (7 October 2010, date downloaded).

Lundqvist, D. & Ohman, A. (2005). Emotion regulates attention: the relation between facial configurations, facial emotion, and visual attention. *Visual Cognition, 12*, 51-84.

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the Penn State Worry Questionnaire. *Behaviour Research and Therapy, 28,* 487–495.

Miller, E. K. & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* 167−202.

Moser, J. S., Becker, M. W., & Moran, T. P. (2012). Enhanced attentional capture in trait anxiety. *Emotion, 12,* 213-216.

Owens, M., Koster, E.H.W., & Derakshan, N., (2012). Impaired filtering of irrelevant information in dysphoria: An ERP study. *Social Cognitive and Affective Neuroscience, 7*, 752-763.

Pessoa, L. Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research, 15,(1),* 31-45.

Richards A. & Blanchette, I. (2004). Independent manipulation of emotion in an emotional Stroop task using classical conditioning. *Emotion, 4,* 275-281.

Righi, S., Mecacci, L., & Viggiano, M. P. (2009). Anxiety, cognitive self-evaluation and performance: ERP correlates. *Journal of Anxiety Disorders, 23,* 1132-1138.

Sehlmeyer, C., Konrad, C., Zwitserlood, P., Arolt, V., Falkenstein, M.,& Beste, C. (2010). ERP indices for response inhibition are related to anxiety-related personalitytraits. *Neuropsychologia*, 48, 2488–2495.

Spielberger, C.C., Gorsuch, R.L., Lushene, R., Vagg, P.R., & Jacobs, G.A. (1983). *Manual for the state-trait anxiety inventory.* Palo Alto, CA: Consulting Psychologists Press.

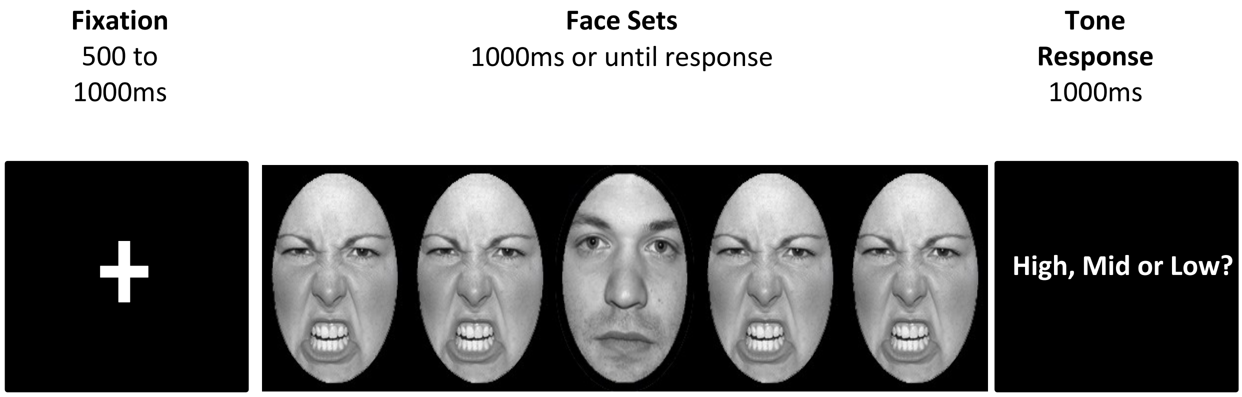
Stout, M.S., Shackman, A.J., Johnson, J.S., & Larson, C.L. (in press) Worry is Associated with Impaired Gating of Threat from Working Memory, *Emotion*

Sussman, T. J., Heller, W., Miller, G. A., & Mohanty, A. (2013). Emotional distractors can enhance attention. *Psychological Science, 24*, 2322-2328.

Tallis, F., Eysenck, M., & Mathews, A. (1992) A questionnaire for the measurement of non-pathological worry. *Personality and Individual Differences, 13,* 161-168.

Van Rijsoort, S., Emmelkamp, P., & Vervaeke, G. (1999). The Penn State Worry Questionnaire and the Worry Domains Questionnaire: structure, reliability and validity. *Clinical Psychology & Psychotherapy, 6,* 297-307.

Yueng, N., (2013). Conflict Monitoring and Cognitive Control. In K.N. Ochsner & S. Kosslyn (Eds.), *The Oxford Handbook of Cognitive Neuroscience: Volume 2: The Cutting Edges* (pp. 275-299). Oxford, UK: Oxford University Press.




**Tone played:** Low

*Figure 1*. An example of a high load trial with negative distractors. During presentation of the faces participants responded with a button press to indicate the gender of the target face (centre) and were instructed to remember the pitch of the tone. Participants were told faces flanking either side of the target face were irrelevant to the task and should be ignored.

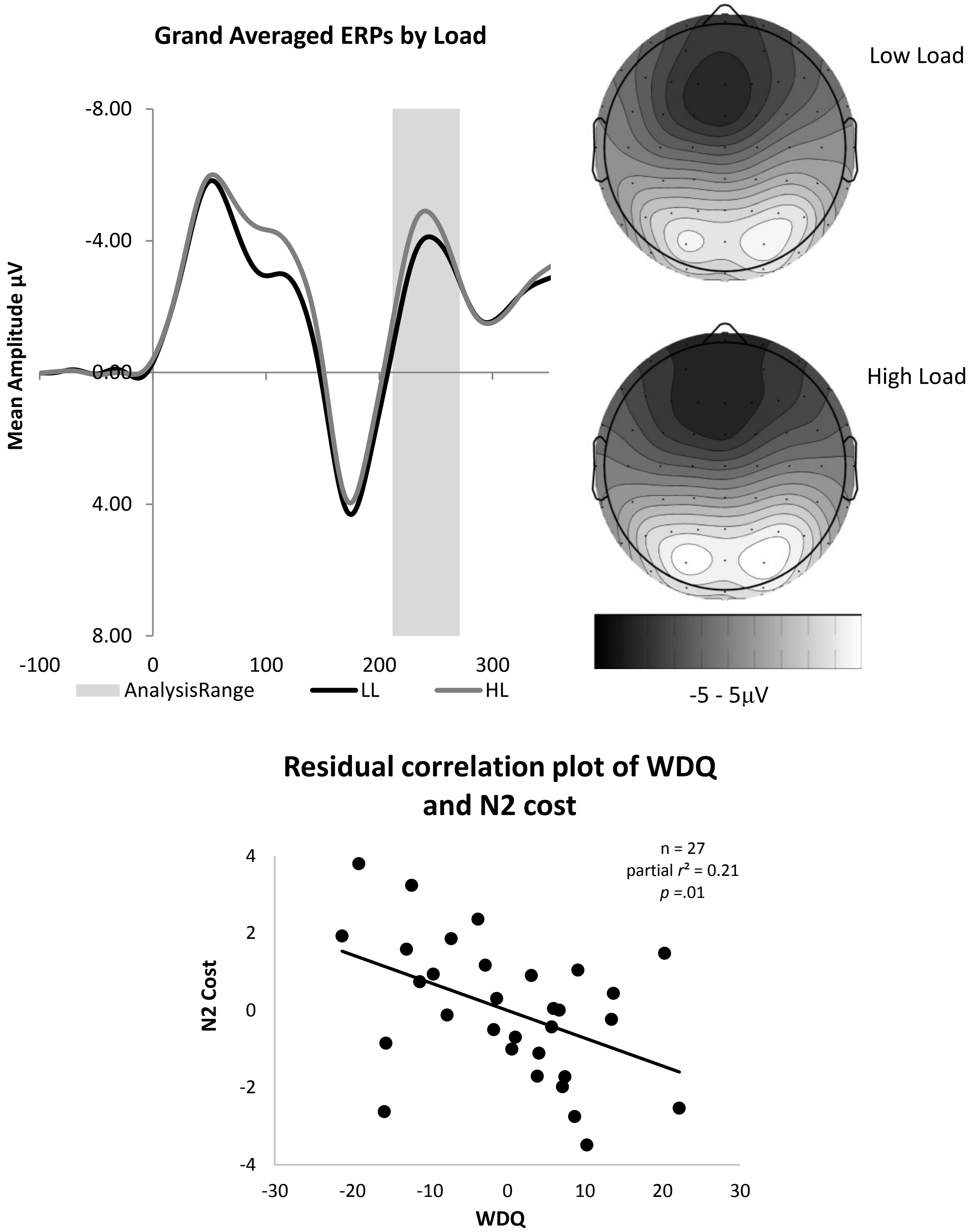



*Figure 2*. Top Left (2a): Grand average waveforms time locked to face sets. Top Right: Topographical scalp map for the N2 across participants. Waveforms and maps are averaged across Frontal electrode sites: Fp1, Fp2, F3, F4, Fz, FC1, FC2, FCz, F1, F2, FC3, FC4. Highlighted regions and maps show the measurement window for the N2 (215-275). Bottom (2b); Partial regression for Worry Domains Questionnaire (WDQ) and N2 load cost (high load minus low load) with regression line.