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Dark Forces in Language Comprehension: The Case of Neuroticism and Disgust in a Pupillometry Study

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Abstract

We report on initial findings from a pupillometry study that investigated the influence of two extra-linguistic variables, namely Neuroticism and Disgust Sensitivity, on auditory language comprehension in adults. Results suggest that: (1) Language comprehension is influenced by extra-linguistic variables and individual differences; (2) the processing of different kinds of linguistic errors, as opposed to clashes with an individual's value or belief system, are influenced by different extra-linguistic variables; and that (3) Disgust Sensitivity at least partially predicts pupillary responses to utterances clashing with an individual's belief system. Results are discussed with regards to linguistic anticipation, cognitive effort and arousal, and resource allocation.

Keywords: psycholinguistics; extra-linguistic information; individual differences; pupillometry; language comprehension; personality; Disgust; neuroticism

Introduction

The field of linguistics has not traditionally focused on what is known as individual differences, or *hot cognition* - for example, emotion or personality. Instead, the focus has been on “abstracting away” or “averaging over” individual differences to be able to make inferences about a population. However, listeners appear to use the preceding discourse and their knowledge of the world immediately to interpret language (Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005), and extra-linguistic influences, such as personality, mood, or accent, are not just “noise,” but can help reveal new information about language comprehension processes (Van den Brink et al., 2010). An individual's personality has also been found to influence aspects of general cognition and daily life, such as academic motivation and the choice of learning style (Busato, Prins, Elshout, & Hamaker, 1998; Jensen, 2015); use of language (Oberlander & Gill, 2004; Pennebaker, Mehl, & Niederhoffer, 2003); response to written errors (Boland & Queen, 2016); speech production in both native speakers and second language learners (Dewaele & Furnham, 2000); and the use of online social media (Park et al., 2015; Wehrli et al., 2008).

Results from experimental psycho-linguistic studies indicate that utterances such as “the girl comforted the clock” can be non-anomalous if the context warrants such an interpretation, from which Nieuwland and Van Berkum (2006) conclude that context can overrule grammatical violations. This is not strictly possible in a purely bottom-up model of language comprehension, where integration with the real world

is thought to happen at a later stage. Research instead suggests that the language comprehension process involves at least some level of top-down processing, with contextual information rapidly being integrated into language comprehension (Kamide, Altmann, & Haywood, 2003; Levy, 2008; Sedivy, Tanenhaus, Chambers, & Carlson, 1999; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Traxler, 2014; Van Berkum et al., 2005).

Van Berkum, Van den Brink, Tesink, Kos, and Hagoort (2008) analyzed ERP responses to statements colliding with a speaker's perceived identity, such as an adult male announcing that he wished he looked like Britney Spears, and found that such statements, clashing with Dutch stereotypes based on age, class, or gender, reliably elicited an N400 component. This component is generally elicited by all content words, but is significantly larger in amplitude for items that are difficult to integrate into the preceding context (Allen, Badecker, & Osterhout, 2003; Kutas & Federmeier, 2007).

Van Berkum, Holleman, Nieuwland, Otten, and Murre (2009) found that statements clashing with an individual's value system, such as “I think euthanasia is an acceptable...” when the participant opposed this practice, elicited a distinctive ERP response just 200-250ms after the onset of the critical word, in addition to an N400 component. These results suggest that, in addition to inferences about the speaker, the *listener's* values and beliefs also play a role in language comprehension.

Van den Brink et al. (2010) found that listeners with high empathy levels showed a significantly larger N400 component in response to socially contradictory information than those with low empathy scores, reasoning that the ability to empathize to a higher degree may encourage a more top-down behaviour, engaging in more prediction based on inferences about the speaker – and hence experiencing surprisal at an unexpected item.

Mood, a more transitory state than personality traits, was also found to affect language comprehension in an implicit causality experiment (Van Berkum, De Goede, Van Alphen, Mulder, & Kerstholt, 2013). Implicit causality verbs, such as “praise” or “apologize,” bias participants as to which of the noun phrases in the sentence is the likely “cause” of an event (Pyykkönen & Järvikivi, 2010). A good mood caused listeners to engage in more prediction as to what the referent might be. This was reflected in a distinctive ERP component

in response to a bias-inconsistent continuation; a bad mood, on the other hand, effectively stifled anticipation. Even a *simulated* mood (Havas, Glenberg, & Rinck, 2007) appears to affect processing speed, such that processing is faster when an individual’s simulated facial expression matched the valence of the sentence.

Summing up, recent research suggests that individual differences such as personality, mood, and world view affect language processing from a very early stage, and not only at a later stage, in what used to be considered a secondary step, referred to as “real-world integration.”

In this paper, we report on initial findings from a pupillometry study that investigated auditory language comprehension in adults, correlating their pupil sizes in response to sentences (non-anomalous. vs. those containing errors or clashes) with measures of Neuroticism and Disgust Sensitivity. Pupil size is considered a non-invasive measure of autonomous nervous system activity (Partala & Surakka, 2003) that is especially responsive to – beyond ambient light levels – cognitive effort, mental workload, attention, and arousal (Gingras, Marin, Puig-Waldmüller, & Fitch, 2015; Goldinger & Papesh, 2012; Just & Carpenter, 1993; Rondeel, Van Steenbergen, Holland, & van Knippenberg, 2015), and that is largely free of task effects. In an auditory experiment with linguistic stimuli, pupil dilation can thus be used as an indicator of the intelligibility and complexity of an utterance (Ben-Nun, 1986; Lõo, van Rij, Järviikivi, & Baayen, 2016; Zekveld, Kramer, & Festen, 2010).

Disgust Sensitivity has, to our knowledge, not yet been investigated with regards to language comprehension. However, being considered one of the most primitive emotions that, for example, serves to protect and organism from novel pathogens, has been found to be strongly linked to feelings of morality, purity, political orientation, and voting behaviour (Inbar, Pizarro, Iyer, & Haidt, 2011; Smith, Oxley, Hibbing, Alford, & Hibbing, 2011). Higher Disgust Sensitivity is generally linked to a more conservative approach, relying more on established socio-cultural stereotypes rather than novel, more liberal ideas.

A proposed tie-in of language processing with cognition more generally comes from Havas et al. (2007), who relate their results to theories in which emotions are assumed to change affordances, the links between perception and action: In this view, a positive mood prepares the body to approach, whereas a negative mood prepares the body to avoid. Under this account, mood and personality could be assumed to influence how strongly a human engages in “approaching” or “exploring”, or how much they stay put and rely on bottom-up information. A related take can be found in the *bioenergetic account*, which suggests that emotional states signal the amount of cognitive resources available for more “costly” behaviours, such as exploration and anticipation (Zadra & Clore, 2011; Van Berkum et al., 2013).

We show below that both Disgust Sensitivity and Neuroticism, as two extra-linguistic variables and components of an

individual’s world view that are not typically investigated in regards to language processing, indeed influence automatic language comprehension processes even in the absence of a conscious judgment or task.

Main Experiment

240 sentences were constructed, 32 of which were unrelated filler sentences. Clashes were distributed among the following conditions (examples are given in Table 1):

MO: 56 sentences total; 28 of which violated subject-verb agreement, resulting in a morpho-syntactic error;

SE: 32 sentences total; 16 of which created a semantic mismatch between the verb and the object, resulting in a semantic error;

SC: 120 sentences total; 60 of which clashed with established gender stereotypes, and as such the speaker’s perceived identity; resulting in a socio-cultural clash (Van Berkum et al., 2008; Van den Brink et al., 2010).

Clash type	Example
MO	She usually drive her car slowly in the snow.
SE	People often read heads for pleasure at night.
S-C	♂I buy my bras at Hudson’s Bay.

Table 1: The template used for item construction, with three example sentences.

All stimuli followed the same syntactic pattern to ensure comparability. Frequency of the critical region, i.e. the main verb plus the direct or oblique object directly following the verb, was controlled for frequency via the *Corpus of Contemporary American English (COCA)* (Davies, 2008).

Items were then recorded by one male and one female native speaker of Canadian English and distributed across four lists of just over 130 items each, counterbalanced for error condition and speaker gender.

82 participants, recruited from the university’s undergraduate Linguistics pool and from the general population, participated in this experiment. Data from six participants (7% of all participants) was removed as their comprehension question accuracy rates were below 80%, and comprehension or attention to the experiment could hence not be guaranteed; or as information given on the language background questionnaire precluded their data from inclusion in the analyses. Data from 728 trials (8.6% of all trials) was removed due to issues during recording that resulted in more than 33% of sampling points on a given trial being recorded as NA. Thus, analyses below are based on the data from 76 participants (males/females = 18/58; native/non-native speakers of English = 61/15; age = 1783; mean [SD] = 25 [12.6] years).

Each participant was presented with one list and, accordingly, each item only once, in just one condition and spoken by one of the speakers. All items were previously rated for acceptability in a separate experiment, by a separate set of

participants, with the resulting average per-item ratings being fed into the statistical models below as a numerical predictor. The distribution of Big Five trait scores within the participants (raters) in this separate norming study was found to be in line with several others reported in the literature, such as those found in Srivastava, John, Gosling, and Potter (2003) and Schmitt and Shackelford (2008).

Each trial began with a one-point drift correct, and, immediately after, the display of a fixation cross at the centre of the screen. The size of the participant’s right pupil was recorded at 250Hz, using an EyeLink 1000 system on a desktop PC, from that the start of the fixation cross onwards. 2000ms later, the audio stimulus began to play, with the latter half of this interval used to create participant-by-trial baselines. Pupil size was recorded until 500ms after audio offset. After a three-second break, in which participants were able to rest their eyes, the next trial began. Attention and comprehension were assessed via simple questions after approximately every fourth trial, and participants were given longer breaks approximately every thirty-five trials.

Post-Tests

Personality traits were assessed via the *Big Five* (John, Donahue, & L., 1991) personality inventory. The Big Five Inventory was chosen for its frequent and continued use in psychological research, and because it assesses various aspects of an individual’s personality rather than just providing one overall score. Of special interest for this paper is the Neuroticism subscale, where high scores are typically associated with a higher tendency to feel anxious, nervous, or tense, and where low scores in contrast are associated with a more even temper (John et al., 1991), as these variables have traditionally been underresearched in regards to language processing.

The participants’ Disgust Sensitivity was assessed via the Disgust Scale - Revised (*DS-R*) (Haidt, McCauley & Rozin, 1994, modified by Olatunji et al., 2007), also used in Ahn et al. (2014). Special interest is given to these two particular scales as prior research has largely focused on the “lighter,” more positively loaded aspects of human personality and cognition, such as empathy. Data on the participants’ language background was collected via a pen-and-paper questionnaire that included questions on items such as age, gender, and languages spoken.

Prior research has reported systematically higher Disgust Sensitivity among women as compared to men (Al-Shawaf, Lewis, & Buss, 2018; Sparks, Fessler, Chan, Ashokkumar, & Holbrook, 2018). In this study, only a non-significant tendency in this same direction was found in a two-sample t-test ($mean_{male} = 1.78, SD_{male} = 0.68; mean_{female} = 2.06, SD_{female} = 0.58; t(28.678) = -1.62, p = 0.12$).

Results

The raw pupillometry data was first downsampled to 125 Hz and then preprocessed in R. Blinks and the 20 adjacent data points were removed using Jacolien van Rij’s `removeBlinks()` function.

Pupil sizes as the response variable were modelled using generalized additive mixed effects modelling (*GAM modelling*, or *GAMM*) with the `itsadug` (van Rij, Wieling, Baayen, & van Rijn, 2016) package in R. All models included random slopes for participant-by-time, and random intercepts by item, to account for individual differences within the stimuli, and for random variance between participants *beyond* the factors of interest. This makes the analyses markedly different from e.g. Van den Brink et al. (2010); Van Berkum et al. (2008), as GAM modelling can capture non-linear interactions between continuous predictors; as it does not assume linear relationships, an assumption that is often unwarranted (Tremblay & Newman, 2015); and as it allows to control for random participant and item effects. Additionally, GAMMs can comfortably model continuous measurements data, such as those obtained in pupillometry studies, without losing information in time-binning or averaging. GAM modelling has been used successfully in experimental psycholinguistics to model the influence of listener experience and the perception of foreign accents (Porretta, Tucker, & Järviö, 2016), and pupillary responses in a naming task (Lõo et al., 2016).

Data in a time window from 500ms before clash onset to 2000ms after clash onset was analyzed, and models included variables such as speech rate and the participant’s progress in the experiment as control variables. Additionally, all numerical predictors were normalized and centered to avoid effects of differential order-of-magnitude scaling between predictors.

Morpho-Syntactic & Semantic Errors

While neither Neuroticism or Disgust were found to significantly influence the processing of semantic errors, Neuroticism was a significant individual difference predictor in a three-way interaction with time and item rating in the morpho-syntactic error model (dev. explained = 9.94%; see

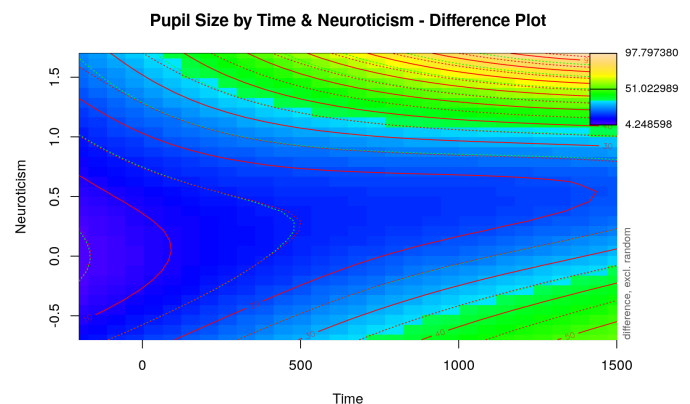


Figure 1: Difference in pupil size between the correct and clashing conditions in response to morpho-syntactic errors.

<i>Parametric coefficients</i>	<i>Estimate</i>	<i>Std. Error</i>	<i>t-value</i>	<i>p-value</i>
(Intercept)	-38.8152	21.1778	-1.8328	0.0668
<i>Smooth terms</i>				
	<i>edf</i>	<i>Ref.df</i>	<i>F-value</i>	<i>p-value</i>
Speech rate	2.9885	2.9998	261.8398	< 0.0001
Trial count	2.9952	3.0000	4055.6671	< 0.0001
Item rating	2.9942	2.9999	476.5416	< 0.0001
Neuroticism	1.0000	1.0000	0.0515	0.8205
Time x rating	15.9104	15.9977	255.7946	< 0.0001
Neur. x time	1.0025	1.0030	0.2502	0.6172
Neur. x rating	15.7562	15.9621	108.7371	< 0.0001
Neur. x time x rating	62.3328	63.7663	88.6382	< 0.0001
<i>Random structure</i>				
Participant x time	673.7516	682.0000	537.2140	< 0.0001
Item	101.6891	102.0000	279.8801	< 0.0001

Table 2: Model output for morpho-syntactic errors. Note that all numerical predictors, except time, were scaled and centered.

<i>Parametric coefficients</i>	<i>Estimate</i>	<i>Std. Error</i>	<i>t-value</i>	<i>p-value</i>
(Intercept)	-25.4912	17.3276	-1.4711	0.1413
<i>B. Smooth terms</i>				
	<i>edf</i>	<i>Ref.df</i>	<i>F-value</i>	<i>p-value</i>
Speech rate	2.9859	2.9998	259.0271	< 0.0001
Trial count	2.9981	3.0000	4287.4004	< 0.0001
Item rating	2.9976	2.9999	673.4162	< 0.0001
Disgust	1.0049	1.0049	0.1383	0.7087
Time x rating	15.8359	15.9884	397.1878	< 0.0001
Disgust x time	3.0779	3.1676	1.6172	0.1174
Disgust x rating	15.8861	15.9860	168.5608	< 0.0001
Disgust x time x rating	62.6458	63.7768	94.6083	< 0.0001
<i>Random structure</i>				
Participant x time	647.7298	666.0000	662.3551	0.0116
Item	101.7037	102.0000	343.1954	< 0.0001

Table 3: Model output for socio-cultural clashes. Note that all numerical predictors, except time, were scaled and centered.

also Table 2).¹

This three-way interaction shows that different Neuroticism scores are correlated with different changes in pupil sizes, which differ further between correct and anomalous items. Specifically, our findings indicate that high Neuroticism scores led to a much stronger pupillary response to morpho-syntactic errors as compared to low scores on this scale (cf. Fig. 1. Like all surface plots in this paper, this plot visualizes the difference in pupil size by time since clash onset (on the x-axis) and Neuroticism scores (on the y-axis) between the clashing and correct conditions. Pupil size is represented as colour on the z-axis: A blue/green hue indicates smaller a smaller difference in pupil sizes, and yellow/orange indicates larger dilation in the clashing compared to the cor-

¹The remaining Big Five traits were tested as well; while elaborating on all results goes beyond the scope of this current paper, Agreeableness was found to be a significant predictor in this same three-way interaction in a model of equally good fit, with low Agreeableness associated with larger differences in pupil sizes.

rect condition).

Further significant main effects in this model include those of speech rate (faster → larger dilation), progress made in the experiment (early trials → larger dilation), item rating (lower → larger dilation), and Neuroticism (higher → larger dilation). It should be noted that the significant three-way interaction between Neuroticism, item rating, and time was found to be significant *beyond* these main effects, and beyond the random effects included in the model.

Socio-Cultural Clashes

In the modelling of socio-cultural errors, Disgust Sensitivity was found to be the single best individual difference predictor tested in an interaction with time and item rating (dev. explained = 9.65%; see also Table 3):² High values, indicating high Disgust Sensitivity, were found to correlate with the

²All Big Five traits were tested here as well; for socio-cultural clashes, Disgust emerged as the single best extra-linguistic predictor.

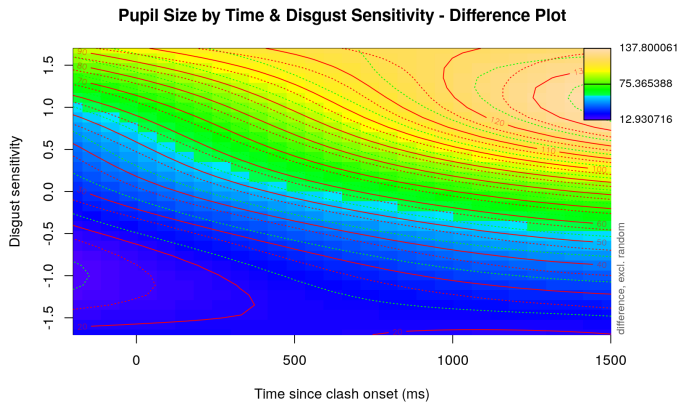


Figure 2: Difference in pupil size between the correct and clashing conditions in response to socio-cultural clashes.

largest pupil dilations in response to statements clashing with socio-cultural stereotypes (cf. Fig. ??).

Further significant main effects include those of speech rate (faster → larger dilation), progress made in the experiment (early trials → larger dilation), item rating (lower → larger dilation), and Disgust Sensitivity (higher → larger dilation). Again, the significant three-way interaction between Disgust Sensitivity, item rating, and time was found to be significant *beyond* the main effects.

Discussion

Our results, specifically the three-way interactions including one of the two extra-linguistic variables, suggest that the processing of morpho-syntactic errors on the one hand, and stereotype-based clashes on the other, are influenced by individual differences and extra-linguistic information. Patterns of influence are not the same across the board, but instead are distinct between different types of errors and clashes. As an example, Neuroticism seemed to only influence the processing of morpho-syntactic errors, whereas Disgust Sensitivity best predicted pupillary responses to socio-cultural clashes. Neither of those two negatively loaded variables of individual differences were found to be significant predictors of pupil size in response to semantic errors.

These results lend further support to theories of language comprehension in which extra-linguistic information is considered early in the comprehension process (Kamide et al., 2003; Levy, 2008; Sedivy et al., 1999; Tanenhaus et al., 1995; Traxler, 2014; Van Berkum et al., 2005), and are not explained well within purely bottom-up theories: Larger pupil dilations for Disgust-sensitive individuals in response to socio-cultural clashes suggest that a statement that is at odds with one’s expectations of purity and morality, and that hence triggers a visceral reaction, results in higher levels of arousal and/or requires more cognitive resources to “unpack.” In this reading, extra-linguistic variables internal to the listener, such as feelings towards or the desire for purity and morality, af-

fect the comprehension process right from the start, instead of being integrated with the sentence in a later step.

Considering the effect of Neuroticism on the processing of simple morpho-syntactic errors, our results add further support to models that include a top-down component; They also support the notion that, very generally, one’s personality affects language comprehension, and that language comprehension does not take place in a vacuum (Van Berkum et al., 2008, 2009). Specifically, our results suggest that individuals that are more prone to feelings of anxiety or nervousness may experience greater distress when experiencing a simple grammatical error. Of note is that morpho-syntactic errors do not clash with experiences or value systems as such, but only violate intra-linguistic rules; This suggests that the listener’s personality seems to affect linguistic processing even when the utterance in question does not directly require value judgments or beliefs to process.

Building on Ahn et al. (2014); Inbar et al. (2011); Smith et al. (2011), our results suggest that Disgust Sensitivity at least partially correlates with sensitivity towards stimuli that, as per existing cultural stereotypes, may be associated more with a progressive and liberal view of the world, and that may trigger stronger reactions in conservative individuals. In addition to further supporting models of language comprehension in which context and experience factor significantly early on, this also meshes with the idea of Disgust serving as a mechanism protecting the individual from novel pathogens carried by members of an out-group: Utterances indicative of out-group status appear to trigger higher levels of arousal, and/or demand more cognitive resources to process.

Within the context of affordances and the bio-energetic account (Havas et al., 2007; Zadra & Clore, 2011; Van Berkum et al., 2013), our results do not neatly tie in with previous research: They suggest that higher Disgust Sensitivity and higher Neuroticism scores may be associated with *more* context-based prediction and anticipation, and hence more surprisal at an unexpected continuation, than lower scores on these scales. These somewhat counter-intuitive results warrant further research, as prior studies have generally found *positive* emotions and moods, such as empathy or an elevated mood, to be associated with more resource availability, prediction, and exploration (Van den Brink et al., 2010).

It should be noted that our results should not necessarily be interpreted as a causal relationship, in that different values of Neuroticism or Disgust Sensitivity “trigger” differences in processing. It is conceivable that a common underlying variable, relating to e.g. resource allocation or to a general predisposition towards other-ness, is causing the effects.

In this fairly new field of research, there is lots of room for both broader and more targeted investigations; we are currently investigating the effects of other extra-linguistic variables, such as the remaining Big Five traits, on language comprehension.

More broadly, future research could, for example, assess the effects of extra-linguistic variables using additional

methodologies, or clashes with different aspects of the listener's identity. Research along those lines may be able to form a more coherent picture, for example in regards to whether it is anticipation or prediction that is modulated by a certain variable, or whether there may be an additional underlying variable that influences both a listener's personality and Disgust Sensitivity, and their linguistic processing at the same time.

Summing up, our results add further support to models of language comprehension that include a top-down component, and to extra-linguistic information and individual differences factoring in language comprehension from a very early stage; and they assessed the influence of Disgust Sensitivity as a "darker" cognitive force on language comprehension for the first time.

Acknowledgments

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