Understanding the time course of privileged access to emotional knowledge in the brain: Evidence from ERPs and representational similarity analysis

A thesis submitted by

Victoria Sharpe

in partial fulfillment of the requirements for the degree of

Master of Science

in

Psychology

Tufts University

February 2020

Advisor: Gina R. Kuperberg, M.D., Ph.D.

Abstract

Emotion plays an important adaptive role in human cognition. For this reason, it has been suggested that emotional information may be privileged over other types of information. That is, emotional information may be processed faster than, and even at the expense of, other semantic features. The present thesis explored this proposal—the affective primacy hypothesis—in two related studies. In the first, we used ERPs to investigate how emotionality impacts the N400 frequency effect. We found that one particular dimension of emotion—arousal—attenuated the effect of frequency, suggesting that infrequent arousing words were accessed more easily than infrequent non-arousing words. In Study 2, we used representational similarity analysis to more directly examine the effect of emotion on semantic processing. We found that neural similarity was reduced for high arousal words in the N400 time window, perhaps indicating that detection of high arousal features "switched off" the availability of semantic information.

Acknowledgments

I am very grateful for my wonderful and insightful committee—Dr. Ariel Goldberg, Dr. Lin Wang, and Dr. Gina Kuperberg. I particularly would like to thank my advisor, Gina Kuperberg, for her patience and guidance throughout this process, and Lin Wang, for her invaluable help and advice. I also want to thank the rest of the NeuroCognition of Language Lab, for all their support.

Table of Contents

Statement of New Contributions	1
General Introduction	3
General Methods	8
Study 1	12
Methods	17
Results	19
Discussion	25
Study 2	26
Methods	30
Results	36
Discussion	38
General Discussion	39
References	43

List of Tables

Table 1. Stimulus properties and exemplars. 10

Table 2. LMER results for main analyses in early and late N400 time windows. 21

Table 3. LMER results for exploratory analyses (using Valence2) in early and late N400 time window. 24

List of Figures

Figure 1. Visualization of ERPs by Arousal and Frequency. 22

Figure 2. Local (loess) regression of N400 amplitudes by Frequency and Arousal. 25

Figure 3. Visualization of RSA pipeline (Wang & Kuperberg, In Prep.) 31

Figure 4. Spatial similarity time series for low versus high arousal. 36

Figure 5. Semantic Similarity by Arousal, for all three methods. 38

Statement of New Contributions

The work presented in this thesis is part of a team effort with contributions from various members of Dr. Kuperberg's NeuroCognition lab. It particularly builds upon work carried out by Nate Delaney-Busch, a former Ph.D. student in the lab, who collected the EEG data that were analyzed in the present thesis, and who reported effects on the late positivity effect (see Experiment 1 in Delaney-Busch, Wilkie, & Kuperberg, 2015).

Dr. Delaney-Busch also initiated the 'avalanche effect' project described in Study 1 of the present thesis. In his analysis, he collapsed across data collected in two separate groups of participants, who each carried out a different task (see Delaney-Busch, 2016, "Situational demands and emotional significance during language processing", chapter 2). The analyses presented in the present thesis, however, focus on the just one of these tasks - the semantic monitoring task.

The following contributions are new to this masters thesis:

- Full single trial ERP analysis of relationships between frequency and emotion dimensions in the semantic monitoring task only within the N400 time window (the spatiotemporal region chosen for analysis was based on the original region selected *a priori* by Nate Delaney-Busch).
- Extension of discussion of relationships between frequency and emotion in relation to emotional primacy.

- Extraction of average within- and between-condition neural similarity values.
- Extraction of single-trial neural similarity values (preprocessing).
- Full representational similarity analysis via cluster permutation ANOVAs on the average within-condition neural similarity values.
- Analyses of semantic similarity of all stimuli using three computational methods: Word2Vec, LSA, and "Random Walk" (De Deyne et al., 2016).
- Discussion of neural similarity as an index of decodable representational content in the EEG signal, and integration of discussion with ERP data.

General Introduction

Emotion, or affect, plays a crucial adaptive role in human cognition—the ability to form emotional associations and quickly evaluate emotional stimuli facilitates a number of functions necessary for survival—for example, avoidance of danger. It has further been suggested that the adaptive role of emotional information in driving approach/avoidance behaviors leads it to be "privileged" over other types of meaningful information (LeDoux, 2012). In this paper, we examine the privileged status of emotional information encoded within words, using EEG to identify the time course with which that information becomes available in the brain. We take two approaches. First, we use a traditional event-related potential (ERP) analysis to ask whether the emotional aspects of words reduce the well-documented effect of frequency on ease of access to word meaning between 300 and 500 ms after word onset. Second, we use EEG in combination with Representational Similarity Analysis (RSA) to further probe differences between emotional and non-emotional words within this time window.

Emotions have been described as "relevance detectors" (Frijda, 1986)—that is, if something in the environment is detected as being emotionally valenced (positive or negative) or arousing (urgent, activating), this indicates that it requires attention and further evaluation. It is established that emotional stimuli capture and hold attention more strongly than neutral stimuli (Compton, 2003). For example, emotional pictures are more easily recognized in an array (Hansen & Hansen, 1988; Ohman, Flykt, & Esteves, 2001; Ohman, Lundqvist, & Esteves, 2001), emotional stimuli are looked at more often and for longer (Calvo & Lang,

2004; Nummenmaa, Hyona, & Calvo, 2006), and the "attentional blink" (the inability to identify a target stimulus that immediately follows another target stimulus in a rapidly presented sequence) is reduced if the second target is emotional (Anderson, 2005).

Emotional stimuli also have been shown to elicit faster behavioral responses than neutral stimuli across a number of tasks (Carretie, 2014, Bradley & Lang, 2007, Kunst-Wilson & Zajonc, 1980). Importantly, this ability to capture and hold attention has been specifically linked to the dimension of emotion known as arousal (Mather & Sutherland, 2011), which signifies urgency or activation, and ranges from low to high.

In the brain, the role of emotion in capturing attention has been linked to the late positivity, a positive-going ERP component that is visible on the scalp surface from approximately 500 ms after stimulus onset and continues for several hundred milliseconds (Citron, 2012; Hajcak, MacNamara, & Olvet, 2010; Kissler, Assadollahi, & Herbert, 2006). This 'emotional late positivity' has been associated with sustained evaluative processing of a motivationally salient stimulus (Hajcak, Weinberg, MacNamara, & Foti, 2012; Weinberg & Hajcak, 2011). It is observed in response to pictures (e.g., Dunning & Hajcak, 2009; Hajcak et al., 2010; Olofsson, Nordin, Sequeira, & Polich, 2008) as well as to words (e.g., Bayer, Sommer, & Schacht, 2012; Delplanque, Silvert, Hot, Rigoulot, & Sequeira, 2006; Fischler & Bradley, 2006), and it can be modulated by both the valence and arousal dimensions of emotion. However, when participants are not specifically evaluating information for emotionality, it appears to be modulated

primarily by *arousal* (Carretié et al., 2008; Hinojosa et al., 2010; Hofmann et al., 2009; Kanske & Kotz, 2007; Bayer et al., 2012; Recio et al., 2014). Indeed, in a recent study, Delaney-Busch and colleagues (2016, Experiment 1) showed that while participants carried out a semantic monitoring task, in which emotion was not directly relevant to task performance, highly arousing words elicited greater late positivity amplitudes than non-arousing words, regardless of valence. This finding supports the behavioral evidence that arousal does not need to be task-relevant in order to capture attention and elicit evaluative processing.

Given the privileged status of emotional information in promoting survival, it has also been also hypothesized that emotional processing sometimes occurs at the expense of other types of 'cognitive' processing. For example, the detection of motivationally salient (i.e., emotional) features may reduce access to other types of information, allowing the experiencer to avoid extensive perceptual and semantic processing, and instead quickly trigger adaptive responses (Zajonc, 1980). For example, if one were to see a snake in the middle of the jungle, it would be beneficial, from an evolutionary perspective, to quickly prioritize information related to its affective evaluation (i.e. dangerous), without deeply processing its other semantic features (e.g., reptile, scaly), in order to allow for a rapid response appropriate to the motivational significance of the stimuli (e.g., removing oneself from harm's way). This prioritization of emotional information at the expense of other types of processing has been termed the affective primacy hypothesis (LeDoux, 2012; Zajonc, 1980).

Though affective primacy has been suggested to influence processing for a wide range of stimulus types, it presents a particularly interesting question for language. Language is abstract and symbolic; understanding it requires a process of decoding meaning from strings of symbols. The time course with which different types of meaning are decoded in the brain has long been of interest to researchers.

We know, from the literature on the late positivity, that attentional resources during word reading are captured by around 500 ms leading to a deeper evaluation of the emotional aspects of meaning in the later stages of processing. However, it remains unclear how emotion impacts an earlier stage of processing between 300 and 500 ms, which is known to capture the process of accessing the semantic features of incoming words (Kutas & Federmeier, 2011; Kutas, Van Petten, & Kluender, 2006). If emotional dimensions of meaning are truly privileged over other semantic information, they should influence processing in this time window. This question has been difficult to address for several reasons; in particular, overlap of the N400 with the late positivity can make effects of emotionality in this time window difficult to interpret.

The present study applies two approaches to shed light on the nature of access to emotional meaning. The data used in both of these analyses were taken from a previously published study (the results of which are described above) that was designed to investigate the effects of emotionality on the late positivity (Delaney-Busch, Wilkie, & Kuperberg, 2016). In this study, EEG was recorded as participants read a large number of single words, presented in isolation, that