Effect of Typicality in Abstract Word Categories on N400 ERP

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1 OBJECTIVES

We investigate the effect of word typicality –the degree of membership of a word to its superordinate category– on the N400 event-related potential (ERP) using a single-trial detection approach based on spatiotemporal beamforming. Unlike the norm in N400 studies, where mostly concrete categories are used (imaginable objects), we considered a total of 6 basic categories: three abstract and unimaginable (emotion, event, illness), one abstract yet clearly imaginable (colour), and two concrete categories, one coherent (mammals) and one incoherent (furniture). Our results show that, independently of word abstractness or concreteness, word typicality has a clear effect on N400 both in terms of amplitude and scalp localization, which in turn is indicative of differences in difficulty of word processing.

2 METHODS

Stimuli were developed to belong to 6 basic categories. For each of the 6 categories, 15 word stimuli were chosen, and a subsequent group of about the same size chosen as "fillers" from random categories of mainly concrete words (out of category word-pairs). The typical and atypical category members, and also the filler words (non-category members), were matched for word length, orthographic neighborhood size, and frequency of occurrence, using the Dutch CLEARPOND software (Marian et al., 2012).

Table 1: means (m) and standard deviation (std) of considered word properties.

	In-category	Non-category
Word length	m=6.7, std=2.2	m=6.7, std=1.5
Orth.Neighb. size	m=2.6, std=3.6	m=1.7, std=2.2
Freq.of occurrence	m=19.2, std=31.7	m=12.1, std=17.2

We recruited 17 volunteers to score, on a scale of 1-5, 90 words based on how typical they thought an exemplar of each category was.

Table 2: Example words for each category.

	typical	**atypical**	**nonmember**
gebeurtenis (event)	feest (party)	kindertijd (childhood)	basketbal (basketball)
kleur (color)	blauw (blue)	amber (amber)	acteur (actor)
meubel (furniture)	stoel (chair)	kapstok (coat rack)	galerij (gallery)
ziekte (illness)	epilepsie (epilepsy)	verslaving (addiction)	ooievaar (stork)
zoogdier (mammal)	olifant (elephant)	vleermuis (bat)	vuilnis (garbage)
emotie (emotion)	droefheid (sadness)	verwarring (confusion)	vliegtuig (plane)

The experimental paradigm was a simple word-pair experiment (semantic priming). The prime word was always chosen to be the label of the superordinate category (i.e., the name of the category). The target is randomly chosen to be either a non-member ("filler") or one of the 15 words chosen as member of that category.

EEG data was recorded using 64 active Ag/AgCl electrodes (SynampsRT, Compumedics, France), according to the international 10-20 system. Two of these electrodes served as ground (AFz) and reference (FCz). The EEG signal was recorded at a 2 KHz sampling rate and downsampled to 250 Hz.

We recruited for our pilot study 12 subjects (5 males, two left-handed, average age was 21.6, std= 1.9). Ethical approval for this study was granted by an independent ethical committee ("Commissie voor Medische Ethiek" of UZ Leuven, our University Hospital). This study was conducted in accordance with the most recent version of the Declaration of Helsinki.

Data Analysis

The EEG data was re-referenced offline from the original ground and reference to a common average reference (CAR), and filtered using a 4^{th} order Butterworth filter in the range of 0.1-30 Hz. A second filtering in the range of 0.1 to 30 Hz was applied to further demote possible remaining artefacts. The data was epoched using windows starting from 100ms prior to the presentation of the stimulus of interest (target) until 1000ms post-onset. The baseline was removed using the average signal

Fahimi, M. and Hulle, M.
Effect of Typicality in Abstract Word Categories on N400 ERP.
In *Extended Abstracts (NEUROTECHNIX 2016)*, pages 6-8

in a 100ms interval prior to stimulus onset. Trials in which the signal exceeded ±150μV where excluded from the analysis. Trials in which mouse button press responses were incorrect for non-member and typical member targets were also omitted, yet incorrect button press responses for atypical words were not omitted.

LCMV Beamformer for Single-trial ERP Detection

The linearly constrained minimum variance (LCMV) beamformer (van Vliet et. Al 2016) is a spatiotemporal filter that relies on spatial- and temporal templates of the ERP collected during a training session (using a proportion of the dataset for training). These templates are formed by subtracting the average EEG recordings of two experimental paradigms both in time (between 350 and 500ms after stimulus onset) and space (electrodes). As our experiment involved three possible outcomes (typical, atypical, and nonmember), we used trials of nonmember and typical targets to maximize the N400 effect. This template is optimized two satisfy two criteria: a) maximal correlation with the actual amplitude of our component of interest (here N400) and b) minimal correlation with interfering signals, such as noise or other ERP components. The template is then applied to each epoch separately (single trial) and the beamformer returns a single value, which indicates the presence of an N400 response for that epoch.

Statistical Analysis

Since we have unbalanced data, a linear mixed effect model was used with N400 response (the output resulting of the beamformer, cf. supra) as an independent variable, and with the following fixed effects for several analyses: relatedness (whether or not our target was a member of the category, irrelevant of typicality), typicality (labels of the targets divided into typical, atypical, and nonmembers), and concreteness (labels of the targets divided based on whether they are members of the concrete or the abstract category). Random effects were targets, primes and subjects. Repeated measures analysis of variance (ANOVA) was performed on the outcomes of the linear mixed effect model. A significance level of 5% was adopted for all analyses.

3 RESULTS

Beamformer Results

Out of the 64 recording channels, we selected a total of 31 channels. Given that only a percentage of the data should be used for training our beamformer template, we needed to choose a proportion of the data, where randomly chosen trials would still show consistent beamformer templates across replications. When we used 60 percent of the data (which is, 30% of the typical and unrelated trials respectively), we achieved an overall stability in both the spatial and temporal templates. Note that we do not use trials with atypical targets to develop the beamformer, because they are expected to be in between the two extreme cases of typical and unrelated, but also because atypical trials in general were less prominent than typical and unrelated ones. To assure statistical stability across replications, we formed the beamformer in 100 iterations and analyzed the mean and variance for the spatial and temporal templates. An example of both templates is shown in fig. 1.

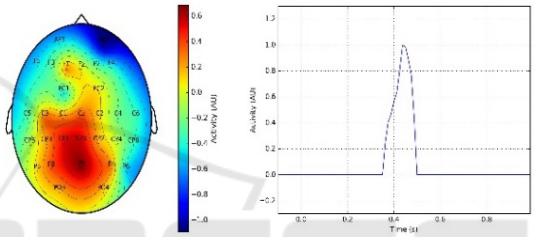

Figure 1: Spatial (left) and temporal (right) beamformer templates.

The first hypothesis we tested was on the general relatedness (target versus nontarget). A one-way ANOVA of general relatedness (including typical and atypical members) against unrelated members revealed a significant difference ($p=0.00175$, $F=5.6743$). When looking for effects of typicality versus atypicality versus nonmember, a significant difference of ($p=0.0008435$, $F=4.8172$) was found, both when all groups were included, but also when the group ‘colour’ was excluded from the analysis ($p=0.004236$, $F=3.1828$). Further pairwise comparison of the groups revealed a significant difference between typical versus atypical exemplars of the categories ($p= 0.002725$, $F=3.7217$). An ANOVA analysis of the effect of concreteness versus abstractness on the N400 amplitude was also significant ($p=0.002589$, $F=3.0919$). Note that this result also holds when we eliminate the group ‘colour’ from the analysis ($p=0.0045245$, $F=2.5084$), which shows that our results apply to both cases of using only abstract unimaginable groups, and when the abstract category includes both imaginable and unimaginable words.

ERP Analysis

The ERPs of four centrally located (Cz, CPz, CP1, CP2) electrodes are plotted in fig. 2. They show a clear distinction between the two different groups of categories, contrary to the lateralized electrodes where the abstract and concrete categories resulted in slightly distorted ERPs.

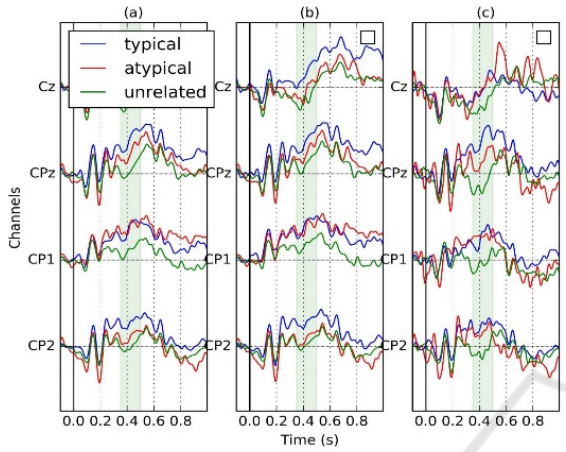

Figure 2: ERP plots of subjects for a) both categories, b) only abstract categories and c) only concrete categories.

4 DISCUSSION

In this study we have investigated the effect of an atypical member of a category on the N400 ERP for both abstract and concrete word categories. We observed a bigger N400 effect for trials with less clear examples of a given category, in accordance with the prototype hypothesis (Rosch, 1975). However, this hypothesis was previously tested mostly for categories of imaginable, concrete words, such as vegetables, flowers, or birds (Fujihara et. Al, 1998). Categories of abstract concepts were given less attention. Here, we evaluated the prototype hypothesis using three abstract categories (illness, event, and emotion) and one abstract- but still imaginable category. The typicality effect was observed in N400 ERP in both the abstract and the concrete categories. The latter has been shown in previous studies (Fujihara et. Al, 1998), but not for the abstract categories. Also it has been shown that the N400 effect is generally larger for concrete versus abstract word-pairs (Kounios and Holcomb, 1994, Tolentino and Tokowicz, 2009). In our study we also found a significant difference between the two groups, both when the comparison was only between abstract, unimaginable words versus concrete ones, and when the abstract category included imaginable words.

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