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Semantic categorization in aphasic patients with impaired language comprehension: An event–related potentials study

Many studies have tackled the question of the organization of our conceptual knowledge in the brain, mainly conducting behaviour studies in healthy and impaired individuals. Animacy and inanimacy are among the most frequently studied categories and there are three main theories or models that explain semantic processing of animate and inanimate objects: the sensory/functional theory, the domain–specific semantic knowledge representation model and the connectionist model of the conceptual structure. Although the event–related potentials (ERP) technique has been used in aphasia research and many studies have used some variation of the semantic categorization task in healthy individuals, to our knowledge there are no studies that were intended to answer the question about semantic categorization in the aphasic population using the ERP technique. The aim of this study is to determine the differences in processing animate and inanimate objects between patients with aphasia with language comprehension difficulties and age, gender and education matched controls using the ERP technique. Results in this study show that the group of aphasic patients with impaired language comprehension have a lower amplitude and a longer latency of the N400 and the LPC amplitude, fewer correct behavioural responses and a slower reaction time on the behavioural categorization task than their controls. It can be concluded that aphasic patients have difficulties in both phases of lexico–semantic processing, the lexical retrieval or recognition phase and the categorization phase. The absence of differences in the processing of animate and inanimate objects in the N400 window and similar topographic distribution for animate and inanimate objects in both groups are consistent with the connectionist model of a single semantic system which claims that the same semantic system is active no matter which category is being processed. However, the observed differences between animate and inanimate objects in the LPC time window in the control group lead to the conclusion that inanimate objects are harder to categorize due to a smaller number of common features needed for the categorization processes.

1. Introduction

Many studies have tackled the question of the organization of our conceptual knowledge in the brain. The first modern studies were conducted in the 1980s and the 1990s and were based on patients with brain injuries. It was noted that animated objects could be selectively impaired independently of the inanimate ones, which led authors to conclude that the semantic system was organised in categories with different neural substrates for each category. In a large number of cases, the inanimate objects were preserved better than the animate objects, the results being based on patients with herpes simplex encephalitis, traumatic brain injuries, cerebrovascular diseases or Alzheimer dementia. However, the opposite pattern was described as well, i.e. difficulties in naming inanimate objects with the preserved ability to name animate ones were observed in patients with fronto–parietal injuries (Gianotti 1990). The same impairments were observed regardless of the task modalities in verbal or nonverbal tasks. For example, a person who could not name a banana could not describe it, draw it or paint in the appropriate colour.

Animacy and inanimacy are the categories that were most frequently studied, although many authors also studied further divisions within each category. Thus, the category of animacy could be further divided into animals, plants, fruits or vegetables, while inanimacy could then be divided into vehicles, clothes, tools, furniture, etc.

There are three main theories that explain semantic processing of animate and inanimate objects. The *sensory/functional theory* is the dominant view claiming that the semantic system is divided into separate subsystems containing various semantic features (sensory and functional) and that the difference in processing animate and inanimate objects can be explained by the selective impairment of perceptive knowledge in contrast to the functional or associative knowledge (Warrington et al. 1984, Kiefer 2001, Proverbio et al. 2007, Gianotti 1990, Ralph et al. 2003). This implies that the sensory and functional features are not equally significant for different semantic categories and that the selective impairment of visual or functional semantic subsystem will result in different impairment of a specific category. Animate objects are recognised by their structure, i.e. perceptive characteristics, while inanimate objects are more dependent on the functional information relevant for the object (Gianotti 1990).

Warrington et al. (1984) hold a similar view describing a model of representation of semantic knowledge called *modal–specific semantic memory* today also known as *feature–based account*. According to this theory, the conceptual system is not built from categories or domains (animate vs. inanimate), but from semantic features (sensory vs. functional) organized in functionally and neuro–anatomically separate regions. In this model, different sorts of perceptual or sensory–motor information are related to different semantic categories, i.e. different kinds of information are needed to tell the difference between the members of a category. The inanimate objects are thus more related to the functional or motor features while the animate objects are more related to sensory or perceptive ones. In other words, we make distinctions between the members of the inanimate category based on their functional properties while we differentiate between the members of the animate category based on their visual properties. If a brain injury impairs perceptive knowledge, animate objects will be impaired due to the reliance on the visual properties in recognizing category members. On the other hand, if a brain injury disrupts functional knowledge, inanimate objects will be less affected because they are visually very different. The model was developed on an observation of four patients with herpes simplex encephalitis. They were better in recognizing inanimate than animate objects independently of stimulus modalities (visual vs. verbal). All patients had bilateral lesions in temporal lobe. Warrington et al. (1984) claimed that information experienced in one input modality (i.e. visual or verbal) was stored in a semantic system based on the modality of the information, not on the input modality. According to this view, various features of an object, auditory, visual, motor, tactile, and so on, are stored in their respective brain areas. The category–specific deficit is a consequence of selective impairment on the neurocognitive mechanism in charge of the specific feature. There are variants of this theory (Farah and McClelland et al. 1991, Farah and McClelland 1991a, Sitnikova et al. 2006), but all share two main assumptions: (1) there is a modal organization of our conceptual knowledge in the brain (visual, tactile, etc.) and (2) sensory and functional features are not equally important for the animate and inanimate objects. Some authors observed the neuroanatomical correlates corroborating this theory, mainly the fact that the deficits in the animate category were related to lesions in the temporal lobe and the deficits in the inanimate category with lesions in the fronto–parietal lobe (Kiefer 2001, Gianotti 1990). Ralph et al. (2003) described a patient KH with semantic dementia who had bi–hemispheric temporal lobe atrophy and, as a consequence, pure category specific deficit for animacy. Although such cases corroborate the sensory/functional theory, cases with similar lesions, but very different pattern of deficits could be found, as well.

The *domain–specific semantic knowledge representation model* assumes that there is a neuroanatomical and functional division between neuronal circuits that process one semantic category or another (Caramazza and Shelton 1998, Shelton and Caramazza 1999, Caramazza et al. 1990). This means that each category (animate or inanimate) uses different neural networks in which all perceptive, functional or associative information necessary for the identification of a category member are stored. According to this view, the semantic system is organized in the brain at the level of whole objects. Caramazza and Shelton claim that a conceptual domain or category is the main organizational principle of conceptual knowledge, not functional and sensory features. They say that the conceptual system is divided into neuro–anatomically specialized subsystems responsible for the representation of specific concepts as a result of evolutionary pressure. This implies that different categories are localized in different brain areas as a result of their different roles in survival and therefore category–specific impairments should manifest for evolutionary important categories such as people, animals, plants or objects. A large number of cases with impairments in the category of animals, i.e. the animate, speak in favour of this model and take into account the assumption that these brain areas are highly specialized, thus more liable to restricted injury. The impairment of a specific category arises after the injury of a specific neuronal substrate without the impairment of visual or functional characteristics of the category. The specific nature of the impairment is brought about by the categorical organization of knowledge that contains all information necessary for a specific semantic domain. This explains that within the category of animacy concepts of animals could be impaired independently of the category of fruits, vegetables or plants, or vice versa (Lambon Ralph et al. 1998). They also think that the Warrington and Shallice (1984) sensory/functional theory does not reflect the categorical organization of conceptual knowledge, but some accidental consequences of the basic principles not related to the categorical organization of the semantic system. They hold that the selective deficit in the category of animacy is not a category–specific deficit, but reflects category non–specific processing deficits larger for words that are less frequent, unfamiliar or more difficult to discriminate visually, although there are many exceptions to this. Caramazza and Shelton (1998) also claim that in patients with category–specific deficits for animacy, knowledge about visual features for animate objects is not necessarily disproportionally impaired in comparison to knowledge about functional features. However, they do agree that the conceptual system contains some subsystems. The first (sensory/functional) theory claims that these are the two subsystems (i.e. sensory and functional), while the second one holds that the semantic system is organized regarding the knowledge that we have about the categories of objects.

The third approach is the *connectionist model* of the conceptual structure. The connectionists claim that the concepts are represented within a single distributed conceptual system with several brain areas involved in semantic processing subserving all categories. The category–specific deficits occur as a result of the differences in the content and structure of the concepts within a category, not within the conceptual knowledge clearly divided into independent systems (Moss and Tyler 2000, Tyler and Moss 2001, Tyler et al. 2003, Devlin et al. 2002, Durrant–Peatfield et al. 1997, Devlin et al. 1998, Hinojosa et al. 2001). According to the conceptual structure model, the conceptual information is distributed randomly without any category/domain organization, and different categories activate brain areas differently regarding the features that define a particular category. The connectionist model assumes that the structure of a domain and a category is based on similarity, i.e. on the degree of the overlap between semantic features. The concepts that share more features are located closer to each other in the semantic space. Such an overlap of features brings about recognizable groups in the semantic space, groups that correspond to a category or domain. These principles are similar to Caramazza's OUCH ("*organized unitary content hypothesis*") theory, but different in terms of architecture, i.e. organization of the connections between features in a concept. OUCH is focused on the connections that categories have within the same anatomical areas: therefore, the semantic features defining a category member are strongly related. Members of the category of animacy will have more common features due to their perceptive similarity. The larger the perceptive similarity between category members, the harder the identification of a particular category member will be. The perceptive–functional theory agrees on the fact that members of the animacy category share more perceptive features, but it differs regarding the general organization of the semantic system in terms of separate brain areas for different category. According to the connectionist model the areas of conceptual space will develop where similar concepts lie together because they share many highly related common features. The categories that have less common features or sparsely related features will develop into a less defined area within the semantic space. Although the system may look as if it is categorically and domain–wise organized, in this model there are no separate and independent systems that correspond to different categories of knowledge: instead, there are graded and overlapping areas within the semantic space. The key idea is that the concepts in different categories and domains have different internal structure, i.e. that the concepts differ in the number and the sort of features (perceptive vs. functional), in the degree in which these features are similar or dissimilar between the members of a category and in the strength of the connections between different features (Tyler and Moss 2001, Tyler et al. 2003). This model assumes that the key relations between form and function are learned during development as a new–born (Moss and Tyler 2000). The number of connections between common features of a category or a domain and the strength of connections between distinctive features are necessary for an accurate identification of a concept and will affect the probability of the preservation of a concept after a brain injury. This probability thus depends on the unequal distribution of features. In case of animate objects, the distinctive perceptive features are more prone to injury since they are weakly connected to other features of a concept. However, for inanimate objects the connections between distinctive features are numerous and stronger correlated, making them less sensitive to injury while the number of common features are smaller and are less correlated (cf. Durrant–Peatfield et al. 1997). Besides influences of different features and connections between them, some authors also highlighted the important role of severity of brain injury on animate vs. inanimate distinction (Moss and Tyler 2000, Devlin et al. 1998, Tyler et al. 2000), although there are some disagreements about which category will be disrupted after less severe versus more severe brain injury.

Event–related potentials (ERP) and semantic categorization

Event–related potentials represent a summarized simultaneous post–synaptic electrical activity of a large number of pyramidal neurons recorded on the scalp as small changes in the EEG recording (Picton et al. 2000). ERPs are obtained from the EEG signal by averaging the spontaneous brain activity around the triggers that are time–locked with the stimuli (Patel and Azzam

2005, Picton et al. 2000). The results are interpreted in terms of the characteristic ERP components. The N400 component (i.e. the negative wave peaking around 400 ms after the onset of the stimulus) that will be discussed later is regarded as an index of semantic processing (Kutas and Hillyard 1980). It has been shown that the N400 was sensitive to semantic and associative relations between word pairs or in a sentence context; its amplitude is lower for strongly related words and it is higher for words that are not expected or are not consistent within a given context (Lau et al. 2008, 2013). It has also been shown that the amplitude was lower for the high frequency words or for the repeating stimuli. The lower amplitude may reflect a lower post–synaptic potential in the same group of neurons or the smaller number of activated neurons; the longer latency of the N400 reflects later or slower processing (Kutas and Federmeier 2011). However, it is still not clear which processes the N400 really reflects. One of the most viable assumptions is that it reflects the amount of memory search necessary for accessing the word meaning or the amount of lexical search in the mental lexicon (Picton 2000).

Late Positive Component (LPC) is related to the category decision processes and complex semantic decisions (Mehta et al. 2009, Constanzo et al. 2013). It is recorded parietally (Mazerolle et al. 2007) and auditory LPC later than visual (550–900 ms vs. 400–800 ms). However, its manifestation in both modalities implies that it is modality independent. The LPC reflects abstract information processing related to the categorization of the stimulus, processes that are about 150 ms prior to the motor response (Constanzo 2013). Some research indicates that the LPC is of a higher amplitude for animate than inanimate (Mazerolle et al. 2007, Paz–Caballero et al. 2006, Proverbio et al. 2007).

A number of ERP studies on healthy subjects has used categorically related prime–target in a "match–mismatch" paradigm (Iragui et al. 1996, Kiefer 2001, Proverbio et al. 2007, Ji et al. 1998, Ković at al. 2010, Mazerolle et al. 2007) or categorically related prime–target in different experimental tasks, i.e. letter search (Bermeitinger et al. 2010) or looking at differences between different categories applying naming task (Sitnikova et al. 2006). Very few authors have used the superordinate categorical decision task (Costanzo et al. 2013, Paz–Caballero et al. 2006). Most of them have looked at differences in the N400 amplitude and reaction times between different conditions, but some also focused on the LPC or the other ERP component, depending on task and stimulus modality. Kiefer (2001) and Proverbio et al. (2007) used a 'match–nonmatch' paradigm with a pair of words or pictures; the task was for the participants to decide whether the stimuli belonged to the same category or not. The results showed that the visual stimuli were categorized quicker than the verbal and that the categorization of animate objects was faster than inanimate in both modalities. These results indicated that different brain areas were involved in processing different categories and that this result could be obtained in a healthy population, not only in aphasic patients.

The ERP technique has indeed been used in aphasia research. The semantic priming paradigm has been employed often (Hagoort et al. 1996, Sales et al. 2012, Kojima and Kaga 2003), as well as the semantic congruency paradigm typical for eliciting the N400 (semantic match or mismatch of the last word in a sentence, Kawohl et al. 2010), lexical decision task (Kitade et al. 1999) and picture–word matching paradigm (Wilson et al. 2012, Robson et al. 2017). Generally, the results indicate that patients with aphasia with comprehension deficit have longer latencies and lower amplitudes of the N400 effect compared to the healthy controls. The heavier the deficit, the larger the difference. Furthermore, Kawohl et al. (2009) have shown that in patients with severe comprehension impairment, the effect of the N400 is absent in the semantic congruence task while the effect of the N400 has lower latencies in patients with mild comprehension impairment. The authors concluded that patients with severe comprehension impairment do not perform the semantic integration at all, but only note the differences between word frequencies. Similar results have been reported by Hagoort (1996) and Kojima and Kaga (2003). In both studies the reduction of the N400 effect has been larger in the group of Wernicke aphasia than Broca, although some studies failed to show a relationship between behavioural accuracy and the N400 response in Wernicke's aphasia (Robson et al. 2017) or severe comprehension deficits were connected just with the delay of the N400 effect, but not with amplitude reduction (Swaab et al. 1997).

As stated already, many studies have used some variation of the semantic categorization task in healthy individuals, but to our knowledge there are no such studies in the aphasic population. The aim of this study is to determine the differences in processing animate and inanimate objects between patients with aphasia with language comprehension difficulties and age, gender and education matched controls using the ERP technique. As a result of brain injury, aphasia is expected to have a lower amplitude and a longer latency of the N400 and the LPC components compared to control subjects in both categories, and a smaller number of accurate responses and an extended response rate during behavioural responding. It is also expected that there is no difference in the processing of animate and inanimate objects in the control group, but due to the lack of evidence in the literature and the inconsistent results in neurological populations, it is not clear how brain injury will affect processing and distinction between animate and inanimate objects in patients with aphasia.

2. Method

2.1 Participants

The participants in this study were 30 patients with aphasia with impaired language comprehension and 30 healthy controls. Each control was paired with a participant with aphasia by age, gender and education. There were 12 women and 18 men in each group. The average age of the participants was 66.9 (42 to 80) years old. Most of the participants graduated from high school (73%) while 26% were university graduates. The demographic data for all participants with aphasia are given in Table 1.

Age	Gen-der	Edu-cation	Time post–stroke	Location of the CVI
62	M	*HS	67	irrigation area of the left ACM
75	M	HS	6	middle and superior TG cortico–subcortically, posterior part of I, and marginally basal part I of the inferior FG
79	M	HS	6	Insular and TF areas
59	F	HS	64	entire irrigation area of the left ACM and ACP
67	M	**UD	6	FP
74	F	HS	26	irrigation area of the left ACM
75	M	HS	98	irrigation area of the left ACM
58	M	HS	37	TP (hypodense entire ACM)
79	F	HS	14	FTP, BG
61	M	HS	9	Entire irrigation area of the left ACM, ische-mia of the BG, partial hemorrhage of ACM
72	M	UD	13	Posterior part of superior and middle FG, middle and distal third of precentral and postcentral gyrus and insular cortex
42	M	UD	50	Temporoapically, in the area of BG and fron-tobasal I
48	M	UD	85	T and partly P
55	F	UD	7	T posteriorly cortico–subcortically and BG
78	F	HS	14	F left
72	F	HS	6	FT left
52	F	UD	7	left F, in BG and T, and left F smaller SAH
59	M	HS	7	irrigation area of the left ACM including BG, I, anterior T with expansion cranially to F
65	M	HS	6	irrigation area of the left ACM, marginal areas between ACM and ACP, and parietal branches of the left ACA
78	M	HS	6	the front edge of I and the segmental part of white matter – lower part of the inferior FG
74	M	HS	6	irrigation area of the left ACM encompassing BG, I, posterior basal part of FG and anterior half of T lobe
69	F	HS	8	left T, BG, TO and F subcortically and peri-ventricularly
64	F	HS	6	left T cortico–subcortically, I, in the area of BG and along Sylvian fissure
80	M	UD	6	left FT
73	M	HS	8	irrigation area of the left ACM
63	M	HS	8	irrigation area of the left ACM

73	F	UD	10	irrigation area of the left ACM and ACP (inferior FG and TPO)
62	F	HS	9	left FTP
74	F	HS	7	left I,T,P
65	F	HS	10	irrigation area of the left ACM
*HS = High school or equivalent **UD= university degree (B.A.; B.S.; M.A. or M.S.) **Legend:** ACM=arteria cerebri media; ACP=arteria cerebri posterior; T=temporal; TG=temporal gyrus; FG=frontal gyrus; P=parietal; F=frontal; I=insula; BG=basal ganglia; FT=frontotemporal; TPO=temporoparietooccipital; FTP=frontotemporoparietal; TO=temporooccipital				

Table 1. Demographic data for participants with aphasia

The inclusion criteria for the participants with aphasia consisted of right hand dominance, normal hearing, and stroke in irrigation area of the left ACM, auditory comprehension deficits and at least six months of post–stroke period. Aphasia was diagnosed by a speech language pathologist experienced in the field of aphasia in the SUVAG Polyclinic. As there are no standardized diagnostic tests for the assessment of aphasia in Croatia, the application of additional standardized and non–standardized language tests has further verified the patient's linguistic status and the presence of auditory comprehension deficits. The tests used were the Croatian version of the Peabody Picture Vocabulary Test (PPVT–III–HR, Dunn et al. 2010), the Croatian version of the Test for reception of grammar (TROG–2:HR, Bishop et al., 2003), a shortened version of the Token Test (De Renzi and Vignolo 1962, translated and adapted into Croatian by Jelena Kuvač Kraljević) and parts of the PALPA Test (Auditory Lexical Decision: Imageability x Frequency and Auditory Synonym Judgements; Kay et al. 1992, translated and adapted into Croatian by Erdeljac et al. (working materials)).

All participants signed an informed consent form according to the Helsinki Ethical Principles for Medical Research.

2.2. Stimuli and the procedure

The stimuli consisted of 200 words, 100 for each category. The inanimate category contained artifacts ("man–made objects": *furniture, clothes, footwear, dishes, materials, cosmetics, tools, weapons, accessories, vehicles, instruments, household and outdoors items*), while the animate category contained 50 animals *(pets, farm, wild and forest animals, insects, birds, reptiles, rodents, water animals)* and 50 plants *(fruits, vegetables, flowers, spices, trees, cereals)*. Half of the stimuli in each category were highly prototypical members of the category. All stimuli were two–syllable Croatian words (4–5 phonemes) counterbalanced for frequency and prototypicality to avoid the prototypicality and frequency effects (words of high and of low prototypicality contained high and low frequency words, for both animate and inanimate objects). Frequency data were obtained from the Croatian National Corpus (HNK_v30, 2014) while the prototypicality was assessed by an online questionnaire. The questions were to name the most typical examples from the above mentioned subcategories. The questionnaire was administered electronically among 120 psychology and speech and language pathology students. The most frequently mentioned items (occurring in more than 75% of the replies), were chosen for the high prototypical stimuli (for example, *wardrobe, trousers, plate, pot, brick, cream, hammer, motorcycle, piano, plum, carrot, rose, parsley, birch, tiger, owl*). The items occurring in less than 75% of the replies were chosen as low prototypical stimuli (for example, *cheetah, cockroach, rogue, lobster, bassoon, bowl, yacht, wax).*

A professional female speaker recorded the stimuli in a private studio in Zagreb. The recording was processed in the PRAAT programme to adjust for loudness (75 SPL) and to cut the recordings into separate files suitable for an ERP experiment. The average duration of the stimuli words was 610 ms, the shortest being 350 and the longest 800 ms. The experiment was programmed with the E–prime stimulus presentation software (Psychology Software Tools, Pittsburgh, PA) to assure that the stimuli would occur randomly in the participants' headphones. The trigger (the point for the later signal averaging) was set to the word onset. Total inter–trial interval (ITI –interval between onset of one word and onset of following word) was varied depending on response time (ITI was set to wait for the response in order to collect behavioural responses), and there was a 1000 ms interval between the response and the presentation of the next stimulus. Each experiment lasted 13–20 minutes, depending on the duration of the break that was set after half of the stimuli were presented. Before each recording, a great deal of time was spent on instruction. The task was rehearsed using visual aids adjusted for each participant in order to assure the comprehension of the task. The EEG recording did not start unless the task was clear to the participant.

In this study, a semantic categorization task was given to the participants. They had to decide whether the auditory presented words belonged to the category of animate or inanimate by pressing the corresponding buttons on a response box.

2.3. ERP recordings and analysis

The EEG recordings were carried out in the Laboratory for Brain Cartography of the SUVAG Polyclinic in Zagreb. A 32–channel Neuroscan SynAmp system with Stim–2 stimulus presentation hardware was used (Compumedics Neuroscan, El Paso, TX, USA) together with 32–channel QuickCap electrode caps that used 10–20 standard for electrode positions. The EEG signal was referenced on linked mastoids and sampled with 500 Hz. The high–pass filter was set to 0.1 Hz, and the low–pass filter was set to 100 Hz with the 50 dB/octave slope.

Finally, the off–line analysis of the results was done by the Brain Products Analyzer 2 software. The data processing consisted of artifact removal (with the built–in ICA based algorithm), further filtering of the data (low–pass filter to 30 Hz), segmenting the data in the –200 – 1400 ms intervals and averaging them. The electrodes were grouped into three groups, Frontal, Central and Parietal in order to check for distribution differences. Numerical data were exported for the statistical analysis ((M)ANOVA) on amplitude and peak latencies data. The peak latencies were assessed with the built–in function of the Analyzer 2 software for each participant individually while the mean amplitude was calculated for each condition (animate vs. inanimate), for each group (control vs. aphasia) and for three areas of interest, i.e. electrode groups (frontal, central, parietal) for the N400 as the mean voltage in the 350 to 650 ms time window after the stimulus presentation and for the LPC as mean voltage in the 750 to 1200 ms time window.

3. Results

Two electrophysiological effects were elicited by this experimental design, the N400 and the LPC (Late Positive Component). While the N400 is known as a measure of semantic processing, the LPC is generally regarded as a component reflecting late categorization processes (Mehta et al. 2009, Constanzo et al. 2013). The overall results (the waveforms) are shown in Figure 1. The distribution data show a typical N400 effect for the control group: broad negativity with a slight right hemisphere shift. The comparison between the aphasic and control participants on both dependent variables, amplitude and latency (MANOVA), shows a statistically significant difference between groups ($F(2, 51)= 23,15$ $p<0,001$). No statistically significant gender differences were obtained. Repeated measure ANOVA on N400 amplitudes with Group as a between–group factor (aphasics and controls) and Animacy and Position as within–group factor (Animate and Inanimate, Frontal, Central and Parietal position) shows no effect of Animacy, but only the main effect of Position ($F(2, 59)= 9,88$, $p<0,001$). The largest N400 amplitudes were observed on the central electrodes. However, the interaction Position x Group has also turned out to be statistically significant ($F(2, 59)=6,78$, $p=0,003$) which means that the neural substrates of the effect were different in each group. Post hoc analyses for between groups differences in the distribution of the N400 on the scalp, both for animate and inanimate objects, have shown to be statistically significant on central electrodes ($p=0,021$). Figure 2 illustrates these results: the difference in the effect size is clearly visible (with the negativity plotted downwards) in both animate and inanimate conditions with some distributional differences.

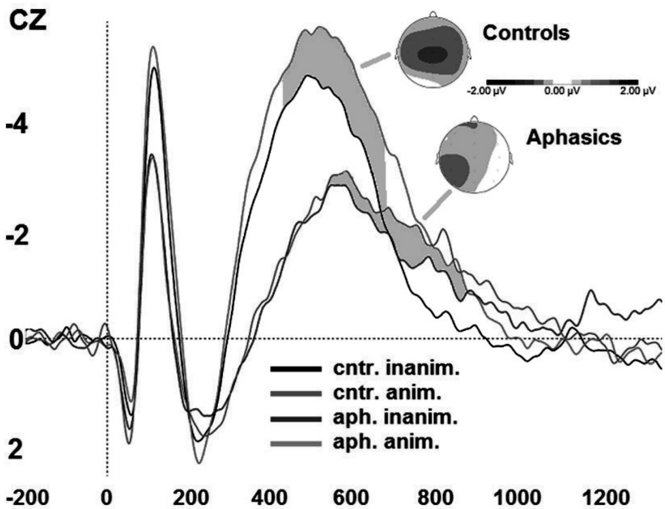

Figure 1. ERP waves and distributional maps for the N400 effect in both groups (grey areas represent the effect in each group)

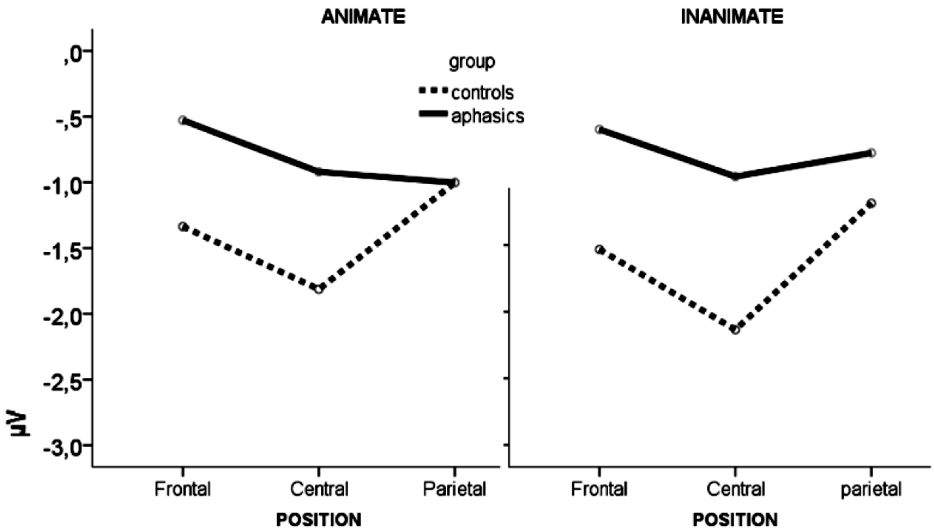

Figure 2. Statistical analysis of the N400 effect

Similar results were obtained for the N400 latencies. On the latency variable, the effect of group has been proven statistically significant (F(1, 59)=6,33, p=0,015) with the aphasia group having longer latencies. The repeated measure ANOVA on Group as between–group and Animacy and Position as within–group factors shows the statistically significant main effect of Position (F(2, 118)=13,70, p<0,001) and statistically significant interactions Position x Group (F(2, 118)=4,90, p=0,017) and Animacy x Position (F(2, 118)=3,1, p=0,05).

Although there was a tendency of shorter latency on parietal electrode sites in both groups in comparison with frontal and central electrodes, groups significantly differ in the N400 latency in parietal electrode sites in both conditions (p=0,001) showing shorter latency in the control group than in the aphasia group. These results are illustrated in Figure 3.

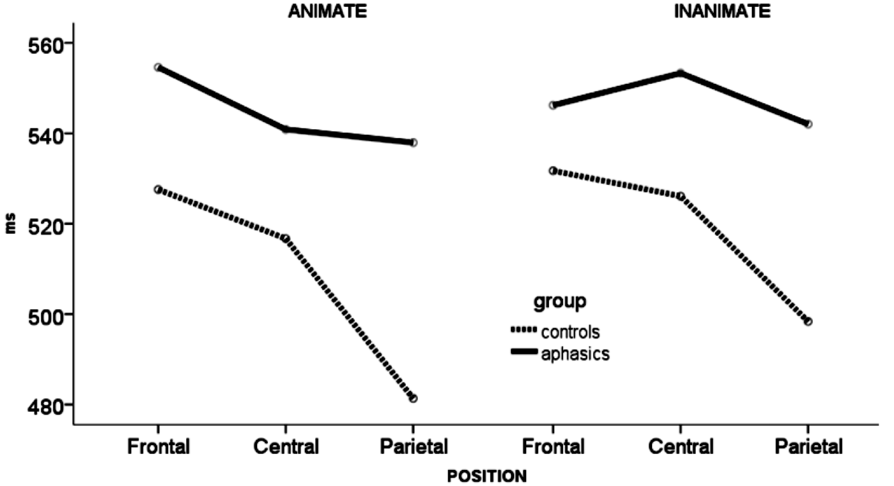

Figure 3. Statistical analysis of Animacy x Group x Position for the N400 latency

Note that the latencies of the N400 are generally higher for both groups (mean = 513 ms for controls and 545 ms for participants with aphasia). This could be attributed to the older age of the participants in general (Cansino, 2009).

Late Positive Component (LPC) has been observed mainly over the left parietal electrodes in the late time window (750–1200 ms) for all participants (Figure 4). Statistical results on mean amplitudes show this pattern of results: the between subject effect of Group was found significant (F(1, 59)=4,51 p=0,038). The LPC effect was elicited in the control group while in the group of participants with aphasia it is either absent or weak, and with no clear distributional differences (Figure 4). Interestingly, here the effect of gender was significant as well (F(1, 59)=4,59, p=0,036) in terms that women had a larger LPC amplitude than men. A statistically significant main effect of Animacy has been obtained (F(1, 59)= 4,1, p=0,048), while the effect of Position has not been found significant. The statistically significant interaction Position x Group has also been obtained (F(2, 59)=4,1, p=0,031). The greatest LPC amplitude in control group was found on the P3 electrode, while the opposite hemispheric pattern has been obtained in the aphasic group (with the greatest amplitude on P4). The results are graphically illustrated in Figure 5.

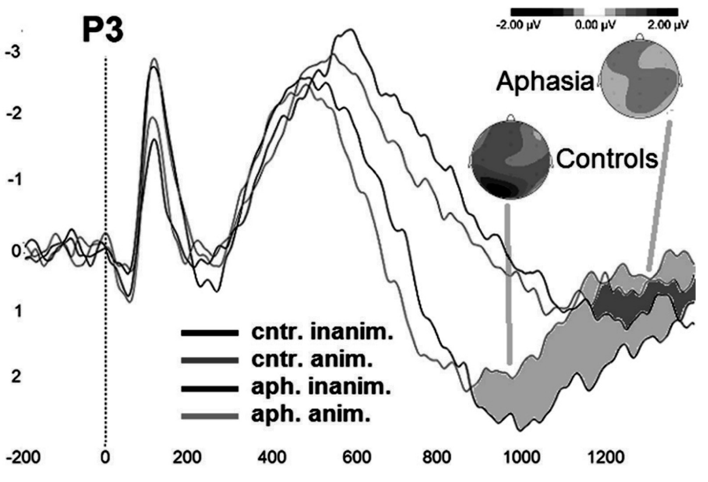

Figure 4. The obtained waveform on P3 and the distribution maps for the LPC (grey areas represent the effect in each group, darker for the aphasic group due to the overlapping with the effect in the controls group)

The latency data show a similar pattern (therefore, the graph is omitted for redundancy). The statistically significant main effect of Animacy has been obtained (F(1,58)=4,234, p=0,044). The LPC latency was prolonged in inanimate condition compared to animate. There is also statistically significant interaction Group x Animacy (F(1,58)=5,346, p=0,024). Aphasic patients turned out to have longer latencies of the LPC component, particularly for animate nouns when compared to the control group. The post–hoc tests indicate that the groups (aphasics and controls) differ only in the animate condition (p=0,038) and that the conditions (animate vs. inanimate) differ only within the control groups (p=0,003).

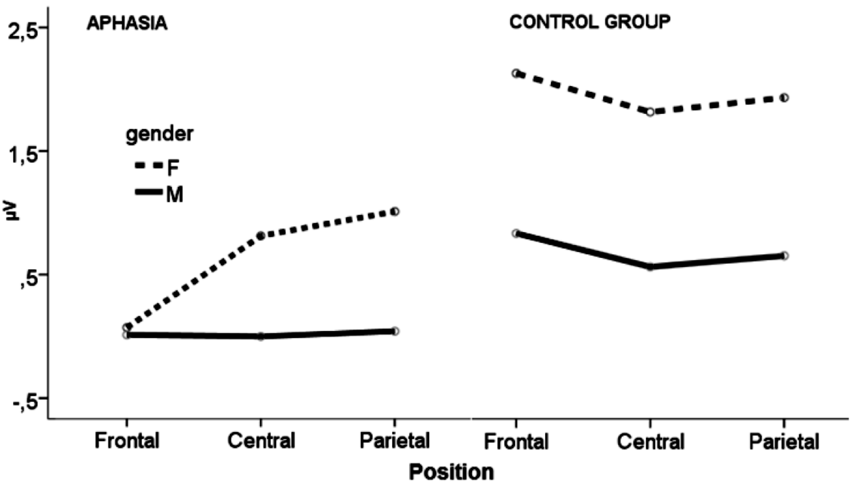

Figure 5. The statistical results of the Late Positive Component (LPC) amplitude

Finally, these results are consistent with the behavioural data (reaction times (RTs), accuracy) of the participants solving the categorization task. The results of the repeated measure ANOVA on Group and Gender as between–group factors and animacy as a within group factor show only the statistically significant main effect of Group for the reaction times (F(1, 56) = 34,23, p<0,01) and for accuracy (F(1,56)= 78,81, p<0,01). Participants with aphasia had significantly lower percentages of correct responses and longer reaction times than the control group (v. Figure 6).

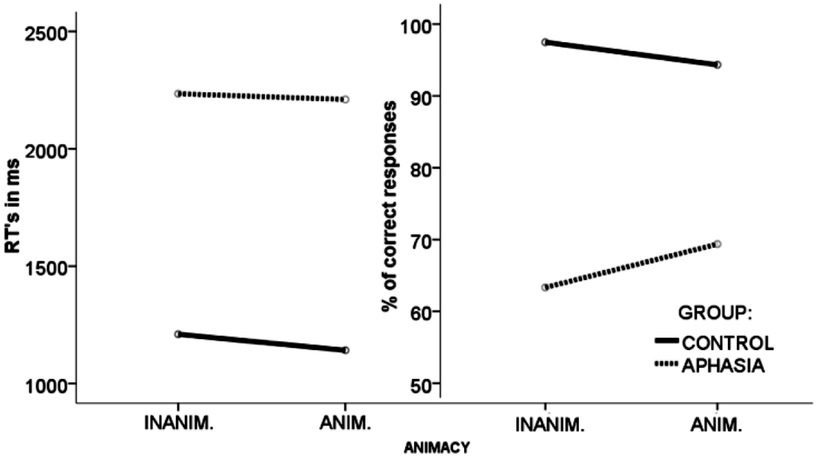

Figure 6. Reaction time (left) and accuracy (right) of the response on the categorization task

4. Discussion

Results in this study show that the group of aphasic patients with impaired language comprehension have statistically significantly smaller and prolonged N400 and LPC amplitude and fewer correct behavioural responses and prolonged reaction time than their age, gender and education matched controls. These results are in contrast to some behavioural studies in which aphasic patients with language comprehension impairment (mostly patients with Wernicke's aphasia) had better results (closer to controls) than patients with Broca's aphasia (Hagoort 1993, Milberg et al. 1987, Blumstein et al. 1982). One reason for this pattern of results could be found in the type of task used in these studies (i.e. lexical decision), a task which requires only implicit language processing by which words are automatically recognized, but are not consciously interpreted and understood or categorized, as in the present study. However, in the study by Kitade et al. (1999), the opposite effect was also obtained where the aphasic group had a greater N400 amplitude than the control group, regardless of the level of language comprehension deficits. The authors suggested that the greater N400 amplitude reflected the increased neural activity in language processing as a result of compensatory activities of areas surrounding the damaged areas and that the prolonged latencies of the N400 amplitude could be interpreted as a delay of neural activity during language processing. There is still much debate and disagreement in the literature about whether the N400 reflects the easiness with which information is integrated into the previously presented context after the meaning of the word has been already activated or if it reflects the processing operation necessary for word activation. Keeping in mind the individual results in the aphasic group in this study, great variability in the N400 amplitude has been noticed between subjects in terms of lower or higher amplitude than in the control group. Reasons for that can be found in Kitade's (1999) claim that some patients make more effort in solving the task, which becomes evident as the larger amplitude, while others are not able to use compensatory mechanisms or they do not make the same effort during task solving. Some authors also emphasized how aphasic patients with comprehension deficits (mostly those with Wernicke's aphasia) could have difficulties in inhibition of automatically activated representations during lexico–semantic processing, resulting in amplitude enhancement (Prather et al. 1997, Wiener et al. 2004).

The results of the present study clearly show that animacy did not influence the amplitude or latency of the N400 both in the aphasic group and in the controls. Despite the overall differences between the groups, it seems that both groups of participants process these two categories in a similar way. Only the Position x Group interaction might suggest that the processes occurred at different locations in the two groups which could depend on the location of the injury and the post–stroke period. Generally, these results are in accordance with the theory of a unitary semantic system (Moss and Tyler 2000, Tyler and Moss 2001, Devlin et al. 2002, Tyler et al. 2003, Ković et al. 2009, Ković et al. 2010), which states that, as a result of brain damage, the semantic system will be disrupted in a global and random style, but not in the way that some category will be selectively impaired. Furthermore, similar topographical distribution for animate and inanimate objects could indicate similar neural substrate of processing these two categories, which is again in accordance with Tyler et al. (2003) claiming that the same semantic system is active regardless of the categories processed. Our results are also in accordance with the results of Hinojosa et al. (2001) who found, by applying the ERP technique, differences in latencies and amplitudes of the recognition potential (RP) between animals and objects as sensitivity to early visual categorization processing (Martín–Loeches et al. 2001). They also found no differences either in ERP amplitudes and latencies or in a topographical distribution between these categories. They concluded that both categories used the same neural areas that were involved in the generation of the ERP response for both categories. Their results confirmed the hypotheses that the semantic system was not categorically organized and that all categories, which differed in their perceptive–functional properties and their dissociation in animate vs. inanimate, had the same access to all brain structures. Similarly to the results of Hinojosa et al. (2003), the findings of this study show neither the difference in amplitude and latency of the N400 component nor in behavioural responses between these two categories.

However, differences between groups and the differences between animate and inanimate objects only in the control group in the LPC time window indicate that the semantic categorization process differs in the two studied groups. Generally, these results are still consistent with the connectionist model (Devlin et al. 2002, Durrant–Peatfield et al. 1997), which also predicts that inanimate objects will be harder to process in a semantic categorization task, as indicated by the larger amplitude of the LPC for the control group, but with the two possible scenarios. According to the first scenario, both processes are affected by the lesion; patients with the comprehension deficits are impaired in all aspects of semantic processing and we see it as a reduction in the N400 and the LPC amplitudes. The second possibility is that the impaired semantic processes reflected in the N400 do not provide a valid input to the later categorization processes reflected in the LPC. This would implicate a two–stage model of semantic categorization: a retrieval or recognition stage followed by a categorization stage in which the difference between animate and inanimate objects is reflected in the difference of the LPC amplitude.

5. Conclusion

Aphasic patients with language comprehension deficits have a significantly lower amplitude and longer latency of the N400 and the LPC components than the control group, and they have significantly more errors and a slower reaction time on the behavioural categorization task. This is consistent with two scenarios: it can be concluded that aphasic patients have difficulties in both phases of lexico–semantic processing, in lexical retrieval or recognition phase and in the categorization phase. Also, it could be that the insufficient input to the categorization phase reflected in the LPC impairs the categorization process and slows down the performance on the categorization task.

The absence of statistically significant differences in the processing of animate and inanimate objects in the N400 window and similar topographic distribution of animate and inanimate objects in both groups are consistent with the connectionist model of a single semantic system which claims that the same semantic system is active no matter which category is being processed. However, the observed differences between animate and inanimate objects in the LPC time window in the control group and the observed differences to the aphasia group lead to the conclusion that inanimate objects are harder to categorize due to a smaller number of common features needed for the categorization processes. Finally, future work will have to include analyses that are more sensitive to individual differences, especially among the group of aphasic patients. Definitely some of these differences might have obscured the view on the semantic processes in patients with aphasia.

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Semantička kategorizacija u afatičnih bolesnika s narušenim jezičnim razumijevanjem: studija provedena uz pomoć metode mjerenja evociranih potencijala

Mnogo se istraživanja bavilo pitanjem organizacije konceptualnog znanja u mozgu, uglavnom primjenjujući bihevioralna istraživanja kod urednih ispitanika i kod osoba s afazijom. Kategorije živog i neživog najčešće su proučavane kategorije, a postoje tri glavne teorije ili modela koji objašnjavaju semantičku obradu koncepata živog i neživog: senzoričko/funkcionalna teorija, model domenski specifične reprezentacije semantičkog znanja i konekcionistički model konceptualne strukture. Iako je metoda mjerenja evociranih potencijala upotrebljavana u istraživanjima osoba s afazijom, a različite su se varijante zadatka semantičke kategorizacije primjenjivale kod uredne populacije, prema našim spoznajama ne postoje istraživanja koja su pokušala odgovoriti na pitanje o semantičkoj kategorizaciji kod osoba s afazijom primjenom metode kognitivnih evociranih potencijala. Cilj je ovog istraživanja metodom mjerenja evociranih potencijala utvrditi postoje li razlike u obradi kategorija živog i neživog između osoba s afazijom kod kojih je narušeno jezično razumijevanje i kontrolne skupine izjednačene po dobi, spolu i obrazovanju. Evocirani potencijali omogućuju dobivanje višedimenzionalne slike kognitivnih procesa koji su u pozadini jezičnog razumijevanja kao i uvid u vremensku dimenziju tih procesa, tj. u različite faze tih procesa. Na taj način, disocirajući dvije faze u procesu kategorizacije pojmova pomoću analize razlika u pojedinim fazama između osoba s afazijama i kontrolne skupine, možemo preciznije govoriti o naravi poremećene funkcije u afazija. Rezultati ovog istraživanja pokazuju da osobe s afazijom s narušenim jezičnim razumijevanjem imaju manju amplitudu i produženu latenciju N400 i komponente LPC te manji broj točnih odgovora i duže vrijeme reakcije na bihevioralnom zadatku kategorizacije nego li kontrolna skupina. Može se zaključiti da osobe s afazijom imaju poteškoća na objema razinama leksičko–semantičke obrade, razini leksičkog prizivanja ili prepoznavanja i razini kategorizacije, što su funkcije koje se povezuju s dobivenim komponentama evociranih potencijala. Odsustvo razlika između obrade kategorije živog i neživog u N400 vremenskom prozoru i slična topografska distribucija za kategorije živog i neživog kod obiju skupina ispitanika u skladu je s konekcionističkim modelom jedinstvenog semantičkog sustava koji tvrdi da je isti semantički sustav aktivan neovisno o kategoriji koja se obrađuje. Međutim, dobivene razlike između uvjeta živog i neživog u LPC vremenskom prozoru, i to samo za kontrolnu skupinu ispitanika, tj. odsustvo efekta LPC u osoba s afazijom, implicira da je pripadnike kategorije neživog teže kategorizirati zbog manjeg broja zajedničkih obilježja potrebnih za procese kategorizacije. Naime, veća amplituda u uvjetu neživog tumači se većim »troškovima obrade«. Odsustvo razlike u osoba s afazijom može biti posljedica deficita specifičnog za kategoriju, ali i neodgovarajuće obrade u prvoj fazi, tj. nedostatnih ulaznih podataka.

Keywords: semantic categorization, categories animate–inanimate, aphasia, connectionist model, ERP, N400, LPC

Ključne riječi: semantička kategorizacija, kategorije živo–neživo, afazija, konekcionistički model, ERP, N400, LPC