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# VISUAL FIELD AND HEMISPHERIC DIFFERENCES IN WORD NAMING AND PICTURE NAMING TASKS: RT AND EEG STUDIES

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**List of publications**

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*People are under misapprehension that the human brain is situated in the head: nothing could be further from the truth. It is carried by the wind from the Caspian Sea.*

*N.V.Gogol*


## Abstract

The study explores visual field differences in word naming and picture naming tasks aiming to reveal what factors influence reaction time in processing of different grammatical classes with different word characteristics, and how. The study also tried to look at gamma behavior in response to visual field and grammatical class conditions and word characteristics. Results of word naming reaction time experiment suggested differential brain strategies in activation of different information sources depending on the field of presentation. The study also showed that regression analysis may be of use in addition to analysis of variance. Results of picture naming reaction time experiment showed not so clear-cut boundaries in the patterns of processing as in word naming experiment. The results were attributed to the overall complexity of the task and, possibly, influence of other factors. Word naming and picture naming experiments on gamma behavior revealed both differences and similarities of word and picture processing within- and between subjects. In addition, analysis of variance and regression analysis suggested that gamma oscillations as a measure of cognitive process might be more informative than reaction time. It seems that gamma may show two different processing strategies: an activation strategy and a processing difficulty strategy, the latter being analogous to reaction time.


## INTRODUCTION

Psycholinguistic research showed an importance of word internal and external attributes in language processing. However, many studies have ignored such a word attribute as its belonging to one or another grammatical class. Unfortunately, there are few studies in psycholinguistics that address the issue of peculiarities in processing of different grammatical classes. More evidence concerning different grammatical class processing exists in neuropsychological and neuroimaging research. Some visual field studies also tried to explore grammatical class differences in word processing. However, too little is done in the domain of picture processing that would take into account grammatical classes. One aim of the present research was to explore influence of different word and picture properties on reaction time using word naming and picture naming tasks. Unambiguous verbs and nouns, as well as verb-derived nouns were taken to study differences and similarities in processing of different grammatical classes and to study what word and picture characteristics and how influence the processing in different visual fields.

Another aim of the study was to explore gamma-band oscillations as a processing measure using the same experimental paradigms. Research on gamma-band frequency and its relation to language and cognition in general has started just recently so, not much is known about gamma relation and sensitivity to language processing. Thus, the EEG experiments were devoted to exploration of gamma reaction to different word properties in different experimental conditions.

The thesis is organised in the following way. Chapter 1 introduces some basic concepts and terms in the domain of visual word and picture processing. Chapter 2 provides some controversial evidence of differential verb and noun processing in neuropsychological and neuroimaging research. Chapter 3 focuses on neuroimaging research on word and picture processing and on brain areas associated with processing stages. Chapter 4 briefly reviews the current state of affairs in the domain of lateralized stimuli presentation in both behavioural and neuroimaging types of methodology and tries to make some predictions concerning the study and outlines the main aims of the study. Chapter 5 and 6 contain reaction time word naming and picture naming experiments adopting different statistical approaches to uncover underlying patterns in verb, noun, and verb-derived noun processing in different visual fields. Chapter 7 combines four EEG experiments examining gamma sensitivity to different experimental conditions. Finally, Chapter 8 concludes the findings and discusses the implications of the study.

# CHAPTER 1. VISUAL WORD AND PICTURE PROCESSING

## 1.1. Factors Influencing Visual Word Processing

Each word in any language possesses many (interconnected) properties/attributes/characteristics that reflect different levels/degrees of word's internal and external structure (or surface and deep types of information). Some of these attributes are, for example, length in characters, phonemes or syllables, word morphological structure, frequency with which a word appears in a language, degree of concreteness/abstractness of a word, imageability (i.e., the degree to which a referent of a word evokes a mental image, that is, the degree of subjective sensory experience), age of acquisition (a rated word-learning age), phonological/semantic neighbourhood density, grammatical class of a word and the like. All the information that a word bears affects word processing in one or another way. Generally, in experiments with response (or reaction) time to a task, reaction time is considered as an integral measure of processing difficulty. That is, the easier the processing, the shorter is reaction time (RT) and the opposite, the more complex the processing is, the longer is RT. Thus, for example, longer words would be read slower than shorter and more frequent words would be read faster than less frequent. A bulk of research consistently finds these relationships between word characteristics and RT. For example, Spieler & Balota (2000) found that word frequency, orthographic length and orthographic neighbourhood were good / reliable predictors of word naming RT. Bates et al. (2001) in a regression analysis revealed that word length, orthographic neighbourhood density, presence of initial fricative, frequency and age of acquisition influenced word naming latency. However, bear in mind that word characteristics are typically interconnected / intercorrelated (e.g., high frequency and high imageability words tend to be learned first; high frequency words tend to be shorter in length than low frequency words, etc.) so that sometimes it is possible to have a confounding variable in the results. Other side of this interconnection is that some effects/impacts may be cancelled/or disappear in a particular condition, for example, in one of the experiments conducted by Monaghan & Ellis (2002) frequency effect disappeared with spelling-sound consistent stimuli but affected RT naming with inconsistent stimuli. So, in particular conditions some word characteristics may be more important than others. Thus, taking into account large number of word characteristics that influence RT, it is very hard or even impossible to control all of them and/or to trace their influence on the processing in terms of its latency. However, it seems, that one of the possible solutions is the type of analysis that was used by Bates et al. (2001). To deal with the colinearity among many variables (word characteristics) they applied factor analysis, extracting in such a way from a large number of variables a small number of factors that combined connected variables into subsets with each variable having its weight within each factor. These factors were then put into regression analysis to determine the unique contribution of each factor into RT variance. To my mind, this is a quite elegant solution of the problem.

To conclude, understanding the impact of various word characteristics is a quite complicated and sensitive matter and should be approached with as much attention and care as possible.

### 1.2. Models of Visual Word Processing

Most computational models of word naming (e.g., Seidenberg, 1995) predict that a word may be read, in principle, without meaning/semantics activation. If the level of orthography-phonology mapping is high enough and/or spelling-sound correspondence is rule-governed, then a word may be read without accessing lexical information. To read irregular words, however, we need an additional information and in this case semantics of a word is activated and takes a part in the articulation process. One of the most recent models (Coltheart et al, 2001) is a little bit expanded (e.g., the model simulates two tasks, lexical decision and word naming; some new information was added such as the position of irregularity effect, etc.) but basically the processing mode and the main logic remains the same: we do not need semantics to read regular words. Though, it should be noted that this model does not contain a semantic system (yet). Thus, the models of word naming take into account more surface word characteristics, including frequency, and claim that the process does not necessarily include lexical access (or semantic and grammatical information of a word). In such a way they ignore "dozens of semantic and/or grammatical priming studies, suggesting that readers do access multiple levels of lexical representations while they are reading target words" (Bates et al., 2001; p.987). It appears, therefore, that the question of whether visual word recognition process can be restricted to a surface level or the meaning of a word is necessarily activated in this process, is still open. I tend to agree to the note of Bates et al. (2001) and tend to accept the 'obligatory meaning activation' hypothesis.

### 1.3. Factors Influencing Picture Processing

Picture naming latency, except the characteristics of a response word (discussed above), depends also on some task-related attributes. First, it is picture-related attributes like the degree of picture visual complexity, picture size and familiarity of the object. Second, it is the degree of relationship between picture and response (for additional information, see Johnson et al., 1996). The most important characteristics of this type are the so-called name agreement (or consensus), image agreement and number of alternative responses to a picture. Usually these characteristics are obtained in a picture naming study, computed after the experiment and added to a picture naming database. Name agreement/consensus is the percentage of people that used the dominant response (i.e., the name that was used for a particular picture by largest number of participants). Image agreement post-test is aimed to obtain a rating of a degree of match between a picture and a mental representation (mental image) of its dominant response. Number of alternative responses, as it is clear from the name, is a number of alternative responses that were given for a particular picture. Usually, consensus and image agreement correlate negatively with RT and number of alternative names -- positively. The dominant response characteristics also influence RT in one way or another. For example, Kremin et al. (2000) found that AoA and name agreement but not frequency and length of dominant responses, made significant independent contributions to the RT variance. Meschyan & Hernandez (2002), however, found that AoA and frequency of the response words made independent contributions to RT and accuracy of naming. Moreover, they found that rated (subjective) frequency is a stronger predictor of RT than is objective frequency. Furthermore, they found that frequency matters more for the late-acquired words, which may mean that late-acquired words have weaker lexical representations thus, benefit more from frequency than early-acquired words. Thus, the contribution of interrelated factors may not be just a cumulative effect on the process latency but a degree of differential within- and between-factor(s) influence on different processing stages.

Next section considers main stages and models of picture naming processing.

## 1.4. Models of Picture Naming

Picture naming is one of the few production-like tasks. That is, in opposite to a more automatic word naming task, where the major role in the process play sub- and/ lexical information, in picture naming task the major role in the process is played by perceptual and conceptual information.

Models of picture naming include (at least) three main stages: object identification (concept activation), name activation and articulation. These three stages are thought to occur more or less sequentially. One of the most influential picture naming models was offered by Levelt (Bock & Levelt, 1994; Levelt et al., 1998; Levelt, 1998; Levelt, 1999). The model contains five main stages: recognition of visual object, concept activation, lemma (which contains grammatical and syntactic information) activation, lexeme (which contains sound form features) activation, and articulation. The activation is unidirectional, spreads from the first to the last stage. On the concept level associated (or semantically related to the target) concepts are also activated. Then from these activated concepts the activation spreads down to the lemma level and activates corresponding lemmas. When the target lemma is selected, the activation spreads to the lexeme level and the word is articulated. In contrast to the five-stage model, the dual coding theory (Paivio, 1990; 1991; Johnson, 1996) contains no such amodal stage as the lemma. Dual coding theory (DCT) differentiates verbal (logogens) and non-verbal (imagens) systems assuming within- and between-system relationships. Thus, a visually perceived picture activates a set of corresponding imagens. When a particular imagen is selected, the activation spreads to the associated logogens. When one logogen receives sufficient activation, the response word is articulated. A key point here is that either a picture or a word may activate various imagens and logogens in different modalities, that is, all the sensory modalities (associated images) and referential and word associations (logogens) may be active. The meaning of a word/picture (stimulus) would then comprise the whole set of activated logogens and imagens (note that the DCT is also applicable for word naming task). In addition to the mentioned advantages, it seems that DCT fits the idea that language incorporates sensorimotor experience (e.g., Gainotti et al., 1995; Bird et al, 2002).

### 1.5. Conclusion

The main aim of this brief chapter was to introduce some basic concepts and terms that will be used throughout the thesis. The main message is that each stimulus (word and picture) has a set of properties that is very important for process characterisation but sometimes hard to control.

One of frequently ignored in psycholinguistic research factors is the grammatical class difference. Note, that especially in English, where many words are grammatically ambiguous (e.g., "bottle"), there is a potential possibility of having a confounding variable in terms of such word characteristics as frequency and imageability. Another possibility may also occur: if the stimuli were controlled for frequency and imageability but not for (unambiguous) grammatical class, then grammatical class may play a role of a confounding variable. Next Chapter reviews some findings from neuropsychological and neuroimaging studies concerning processing of different grammatical classes and factors that influence this processing. I will try to concentrate on noun/verb differences, which is more relevant to the aim of the thesis.

## CHAPTER 2. DIFFERENTIAL PROCESSING OF NOUNS AND VERBS

### 2.1. Neuropsychological Evidence

Most neuropsychological data agree on the so-called double-dissociation between noun and verb production and comprehension. The findings suggest that different brain mechanisms of the language-dominant left hemisphere are involved in noun/verb production and comprehension. In particular, left temporal lobe may play a critical role in noun processing, and left frontal lobe -- in verb processing. For instance, Daniele et al. (1994) presented a study on three brain-damaged patients. Two of the patients had a left frontal lobe atrophy and were impaired in comprehension and production of verbs, and one patient had a left temporal lobe lesion and was impaired in noun production and comprehension. Daniele et al. (1994) proposed that distinct neural systems in the left temporal and frontal brain regions may play a crucial role in production and comprehension of these two grammatical classes. Damasio & Tranel (1993) reported similar results, concerning production, studying three brain-damaged patients with lesions in the left frontal and left anterior temporal regions. Patients were presented with a set of pictures and were asked in one session to name them and in the second session to write down the name without overt articulation. The experiments showed that subjects had rather retrieval problems (associated with word forms) and not problems with lexicon (associated with conceptual information) which was confirmed by the results of repeated sessions. Analyses of frequency and length of the words showed that neither factor was responsible for the results. Damasio & Tranel (1993) suggested that mediating systems between word form and its concept are anatomically different for nouns and verbs: the system of concrete nouns is close to concrete concept representation and is located in left anterior temporal region, whereas system of verbs is close to movement representation and is located in the left frontal lobe. A survey by Gainotti et al. (1995) also showed that typically, the damage of left frontal lobe was resulted in verb impairment, and damage of left temporal and the posterior associated areas were associated with noun impairment. Based on the neurological data, the authors suggested that sensorimotor mechanisms could have been involved in the process of acquisition of impaired grammatical categories and that damaged brain regions could subserve these mechanisms. Thus, motor functions could have contributed to the acquisition of action names and sensory information could have contributed to the acquisition of object names. Other studies of brain damaged subjects (e.g., Garamazza & Hillis, 1991; Hillis and Caramazza, 1995), based on a dissociation between written and spoken output of nouns and verbs, conclude that not only orthographic and phonological word forms but also grammatical class are parts of lexical system in the brain.

However, as Bird et al. (2001) note, control for imageability and for unambiguous nouns and verbs were lacking in almost all research. The above mentioned studies are not exceptional in this sense. Bird et al. (2002), using a picture naming task, clearly demonstrated that grammatical class differences in patients production disappeared when imageability was controlled. Thus, they asserted that grammatical class deficit was the result of confounding grammatical class with imageability. The authors support the view that there is no specific brain structure responsible for a grammatical or semantic category, rather, some (sensorimotor) neuroanatomical structures correlate with the mechanisms of acquisition of these categories and their representations. They also propose that grammatical and semantic category deficits are on the same semantic level. Another study that included imageability as a factor is done by Luzzatti et al. (2002). On a large number of patients with different degrees and types of impairments using a picture naming experimental paradigm the authors demonstrated that in the majority of cases the noun/verb dissociation was sensitive to frequency and imageability factors. In particular, word frequency cancelled dissociation pattern in the majority of patients, which showed a verb-superior behaviour, and word imageability made dissociation pattern to disappear in the majority of patients with noun-superior behaviour. Note, that although nouns and verbs were equalised by items' age of acquisition and familiarity ratings, Luzzatti et al. (2002) failed to match verbs and nouns by frequency and imageability. Verbs were of higher frequency than nouns, and nouns were of higher imageability than verbs. The authors' main conclusion was that simple noun-verb dissociation cannot be taken as a proof for separate functional and anatomical "store" for nouns and verbs. These lexical items differ also in their underlying properties both at the lemma and at the semantic/conceptual levels.

To summarize, it is still unclear whether the verb/noun dissociation is on grammatical or semantic level or even other though, it should be noted, that the two concepts are closely interrelated. Probably, sensorimotor experience/information may play an important role in noun/verb processing in normal subjects. It is also possible that processing of different grammatical classes is governed by different factors. Thus, one implication is to try to take into account most important psycholinguistic variables in order to have more informative picture. Concerning associated with noun/verb deficit brain areas, probably, it would be worth to keep in mind, that different brain areas relate to language processing to different degrees and with different types of involvement and that, as Dick et al. (2001) pointed out, the same "language" regions "are also involved in the mediation of processes that language shares with other domains, including specific forms of memory, attention, perception, and motor planning" (p.760).

### 2.2. Neuroimaging Evidence

There are few studies addressing the issue of noun/verb differences and the factors that influence the processing. Koenig & Lehmann (1996) applying a spatial mictostate analysis to the ERP revealed that silently read German unambiguous nouns and verbs of the same frequency and length differed in their functional microstates. This means that different, though unknown steps of information processing were peculiar for noun/verb differential processing. The differences were obtained in a quite early time window (116-172 ms from the stimulus onset), thus, showing early discrimination and late homogeneity of the processing (or rather/may be late impossibility of being distinguished by the method). They concluded that different neuronal populations were involved in the processing of these grammatical classes. In agreement with these data in the sense of verb/noun differential processing is also work done by Pulvermüller et al. (1999) and by Pulvermüller et al. (1996). Both studies addressed the issue from a point of view of Hebbian cells assemblies that is, cortex is a huge associative memory network, frequently (co)activated neurons form cell assemblies which, in their turn, may form functional units, distributed in the brain. Thus, they suggest, that verbs highly associated with action may form functional units, distributed over the areas, including those, related to movement/motor activity, and nouns highly associated with visual sense, would form functional units that include visual/occipital areas. To test this assumption, the authors used lexical decision task taking as a measure high frequency cortical responses (gamma oscillations) that are event-related and are involved in high-level cognitive processes (Pulvermüller, 1996; Pulvermüller, 1999) and event-related potentials (Pulvermüller, 1999). Frequency and length of used nouns and verbs were controlled. In addition, a pre-test for visual and motor associations was also conducted in order to insure high visual/motor associations of the items used. The results of the experiments indicated that, indeed, nouns elicited more activation in occipital areas whereas verbs -- in central areas, close to motor cortices. Interestingly, the noun/verb difference was obtained only in low gamma band, around 30 Hz (ranged from 25 to 35 Hz) and not in higher frequency bands. Thus, other frequency bands appeared to be insensitive to the differences in processing. Overall, the results were consistent with the view that in noun processing neurons in or close to visual areas are activated, and in verb processing neurons in or close to motor areas are activated. Continuing this line of research, Pulvermüller et al. (2001) investigated differences between verbs referred to actions, performed by face, arm and leg. They found strong cortical activity in areas associated with the representation of these body parts in the brain. So, once again the results supported the associative learning principle and showed that the basic semantics of single verbs may be reflected and revealed in the EEG brain responses.

Somehow different approach is presented by Wise et al. (2000). They varied imageability of auditory and visually presented nouns to study the impact of imageability to brain areas. The tasks were either to pay attention and understand the heard or seen words, or to compare the meanings of visually presented triplets of nouns. Using positron emission tomography (PET), they demonstrated that temporal lobe was sensitive to the imageability of nouns with slightly higher activation in left hemisphere than in the right one. The activation in response to imageability was more pronounced for low frequency words than for high frequency. They argued that temporal lobe is involved in word perception, semantic and episodic memory processes and attributed these and possibly other high-order cognitive processes to the results. Moreover, the authors suggested that via temporal lobe passes a route of early (concrete) noun acquisition since ventromedial temporal regions have connections to visual, auditory and somatosensory association areas. Thus, although Wise et al. (2000) did not control specifically for noun visual arouses, their results did not show visual area activated with high imageable nouns. The differences in the results may be attributed to the differences in the tasks, stimuli and methods used.

Pulvermüller (1996) presented in more details the concept of cell assemblies concerning language processing giving additional information and experimental results. I will consider some related to the present study points. First, that Hebbian associative learning framework suggests that the cell assemblies related to language processing are distributed over both hemispheres although not equally but to some degree, depending on "semantic richness" of lexical items in terms of the strength of associated sensorimotor modalities. Note, that this account is quite close to dual coding theory (Paivio, 1990; Paivio, 1991) though Pulvermüller (1996) notes that DCT does not support the necessarily contribution of right hemisphere to the processing of motor words while it supports the contribution of right hemisphere to the processing of associated with words images. I would rather disagree with this note. First, Paivio (1991) repeatedly stresses the non-verbal sensorimotor (imagen) system that is orthogonal to the verbal (logogen) system. Thus, the imagen system incorporates not only all sensory-associated images but also motor images. Paivio (1990) associates imagen system more with the right hemisphere and synchronous mode processing mode, and logogen system more with the left hemisphere and sequential processing mode. Although he does not discuss motor-related verbs specifically, he assumes that "covert motor processes operate on mental representations with synchronously organized sensory properties" (Paivio, 1990; p.72). What Paivio (1991) calls "motor" and refer to the verbal system is, as a matter of fact, a part of articulation system. Overall, I think that in this point the Hebbian approach is similar to DCT to a high degree.

The second point I would like consider, is the note of Pulvermüller (1996) that Hebbian framework assumes that one functional unit incorporates semantic, syntactic and word form features that will be activated at once/simultaneously with the presentation of target stimulus. That is, all these different word features would be activated and accessed at one and the same time. Concerning word processing, though it could be argued about the mode of the process (a serial or a parallel one), the same Pulvermüller et al. (2001) found in a MEG study a word semantic activation before its grammatical encoding. It could be accepted that all the word features may be activated at once but it seems that the access to these features is highly dependent on the activation level. That is, weakly activated features had lower probability and possibility to be accessed than strongly activated. Thus, the activation level may be highly dependent on time, except the dependency on the features themselves. Although Pulvermüller (1996) does not discuss picture stimuli (after all, why functional units should concern only words?), I would refer to Johnson (1996) to remind that picture naming is processed more or less sequentially, from object recognition to articulation (for an experimental evidence of picture naming sequential processing see Bock and Levelt (1994)). Thus, even if a functional unit contains all the word features, it seems implausible that all of them would be activated and especially accessed at once. Whether the activation system is a "threshold" one, "cascaded", "parallel" or something else, it seems that different features influence processing differently, with different degrees and "success", depending on their strength and degree of their interaction/interrelation, on other possible processes that would be involved, on the experimental context and on the anatomical and cognitive differences between the subjects.

### 2.3. Conclusion

Overall, it seems to be clear that differential noun/verb processing may or, rather, is highly dependent on word's superficial and intrinsic properties. The brain areas, associated with the processing may differ from study to study that reflect different approaches and experimental paradigms.

The next Chapter will briefly review some main findings in visual word and picture processing. I will try to focus on main stages of processing and on associated with these stages brain areas.

# CHAPTER 3. NEUROIMAGING STUDIES ON VISUAL WORD AND PICTURE PROCESSING

## 3.1. Word Processing

In an attempt to find out not only *where* but also *how* reading is accomplished, researchers use different techniques and experimental paradigms, which sometimes brings to controversial findings though, maybe, exactly these variations in the results may help us to understand how the brain works. Fiez & Petersen (1998) in their review carefully selected studies where approximately the same (single word reading) tasks were used. In spite of this, they found that the results vary. The authors attributed the variations to different techniques used (PET and fMRI), different methods of analysis and individual differences of the subjects. They warn us that there is no reason to believe that divergent brain regions identified in the review, delineate single functional areas and that various interpretations may be correct. However, Fiez & Petersen (1998), based on the comparative analysis, suggested that left frontal cortex is involved in the orthography-to-phonology transformation process. In addition, they proposed that motor cortex is involved not only/just in motoric aspects of speech but also in the process of transformation from phonological to articulatory representations. In agreement with Fiez & Petersen (1998) analysis, Burton

(2001), using fMRI technique, also found that activation of inferior frontal gyrus (Broca's area) is related to the aspects of phonological processing. In particular, tasks, required visual phonological judgements, showed an activation pattern in anterior and inferior parts of the Broca's area, while auditory speech segmentation required for phonological judgement tasks, resulted in the activation of superior and posterior parts of the inferior frontal gyrus. Burton (2001) suggests that distinct phonological processes are mediated by the inferior frontal gyrus.

Other studies that used different tasks, also (partially) agree that inferior frontal region is involved in the process of orthography-to-phonology conversion. For instance, Fiebach et al. (2002), using a lexical decision task and event-related fMRI, found, that this region participates in the orthographic-phonological transformation and, since they observed activation of the Broca's area for low frequency words, they proposed that this area is also involved in the process of lexical selection. In addition, the results of Fiebach et al. (2002) suggested that bilateral occipito-temporal and posterior left middle temporal gyrus were involved in the pre-lexical processes since the activation was independent on frequency of the words. Note, that the used words were not controlled for either imageability or concreteness; the authors admit that about half of the stimuli were abstract nouns. A study that involved silent and aloud reading (Hagoort et al., 1999) suggests that middle temporal gyri participated in the phonological and semantic retrieval while left inferior frontal gyrus was involved in the sub-lexical coding. In contrast, other research (e.g., Snyder et al., 1995; Thompson-Schill et al., 1997; Posner & Pavese, 1998; Roskies et al., 2001) has shown that in response to visual words, frontal areas (and partially left pariotemporal and temporal regions) were actively involved in semantic activation, more specifically, in meaning selection and retrieval. These studies used various semantic and lexical demanding tasks including word generation. Gabrieli et al. (1998) reviewed studies that were focusing on left prefrontal cortex and its involvement in memory and language processes, and concluded that left inferior prefrontal cortex is actively involved in a domain-specific semantic working memory processes. Thus, it is evident that different tasks prompt an activation in the same or closely related areas that was attributed to several different types of information processing. While some authors (e.g., Bentin et al., 1999) propose that different neural populations are responsible for a particular aspect of word processing, maybe, it would be possible to assume that not different but the same (or rather overlapping) neural populations are "firing" in a respond to a task executing the most important for the moment function(s).

### 3.2. Picture Processing

While most researches agree that picture naming process is more or less a sequential one and provide experimental support for a serial or cascaded but not parallel mode of processing (e.g., Schmitt et al., 2001; Schmitt et al., 2000; Levelt, 2001; Rodriguez-Fornells et al., 2002), the question of relation of cortical sites to the corresponding stages of processing is still an open and a controversial one.

Levelt et al. (1998) were able to distinguish activation time windows for each of the four main stages (visual processing and concept activation, lemma activation, lexeme stage, and phonetic and articulatory processing) and to relate a MEG analysis to these time windows. The results have shown that during an object recognition stage occipital areas were mostly activated with a dominating activation in the right hemisphere. In lemma stage time window activation was found in occipital, parietal and temporal areas, with a clustering of activation sources in the right parietal cortex (7 out of 8 subjects). The authors attributed the right parietal activation to the possible working memory and visual attention involvement into the lemma selection. Phonological encoding stage showed activation in Wernicke's area. Levelt et al. (1998) suggested that Wernicke's areas is involved not only in the phonological encoding but also in other aspects of production such as self-monitoring. Finally, the last stage of the process activated sensory-motor cortex and parietal and temporal lobes. The authors did not discuss the first and the last stages in detail, instead, they focused their attention on the lemma selection and phonological encoding stages. Levelt et al. (1998) argued that different neural populations were involved in these different stages. Interestingly, although they varied frequency of the words (high and low), the results showed no frequency sensitivity of activation patterns between and within the subjects. Thus, the main findings were that in lexeme selection left posterior temporal lobe and in lemma activation right parietal cortex played a role in the processing. Later studies confirmed these results (Levelt, 2001; Maess, 2002).

In contrast to these studies, other experimental evidence, using PET, suggests that temporal lobe is rather involved in not only lexical retrieval but also in some semantic (including visual-perceptual) processing in picture naming (e.g., Murtha et al., 1999; Damasio et al., 1996). Moreover, Murtha et al. (1999) did not find parietal activation during picture naming and found an activation of left middle and left inferior frontal gyrus, attributing this activation to semantic and/or phonological activation. The contradiction with the previous results (Levelt et al., 1998) may be explained by different techniques and methods used. Although this explanation is the easiest and the broadest one and may cover any contradiction that naturally occurs in brain processes studies, it seems that we just do not have any other reliable explanation for such a complex brain system, except for discussing the approaches, methods, variables, stimuli and the like.

### 3.3. Conclusion

Overall, word and picture processing studies brought to quite different results in activation and explanation patterns. Taking into account that some active brain areas overlapped not only within the same task or the same stimulus modality but also between (e.g., left frontal lobe activation in the two, word and picture processing) and taking into account some other studies that found overlapping areas in comprehension and production*, the following conclusion may be drawn. The complex language processing may require a conjoint activity of both, different and widely distributed and closely spatially related/overlapping/same areas that are not necessarily executing/reflecting a single specified function. Instead, these regions may function differently depending on a task and variables (broadly speaking) and on other, "non-language" processes that are inevitably involved in the whole process.

## CHAPTER 4. VISUAL FIELD STUDIES

### 4.1. Introduction

Traditional neuroscience regards left hemisphere as exclusively competent in language. Right hemisphere is thought to have little if any control over language production or comprehension. However, experimental research with normal or damaged subjects tends to indicate that the role of right hemisphere (RH) is rather underestimated. Studies of RH damaged patients indicate that these patients have difficulties in understanding figurative language, jokes, in understanding and producing appropriate discourse structure and in interpreting prosody (Zaidel, 1990; Springer & Deutsch, 2001). Thus, probably, the RH is not only able to

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* For example, Ilmberger et al. (2001), based on the results of electrical stimulation of cortical sites of 14 patients and using Token Test and picture naming task, revealed that comprehension and production processes involve common left hemisphere areas. Comprehension (Token Test) disturbance was associated with frontal and temporal regions, and production (picture naming) -- with frontal, temporal, and parietal areas.

comprehend written and spoken language but it plays an integral role in language processing (for an experimental support, see Federmeier & Kutas, 1999; Federmeier & Kutas, 2002).

Research on hemispheric differences in normal language processing is devoted mainly to the question, whether or not the two hemispheres have access to the same or different lexical information and/or systems and what factors or word characteristics play a role in hemispheric processing. Typically this kind of research employs visually lateralized (bi- or unilaterally) stimuli presentation. The underlying idea of this methodology is that if to fixate a gaze to the center of the screen then both eyes will see both visual fields but the information from each visual field will go through visual pathways to the primary visual cortex of just one hemisphere. So, when a stimulus is presented to the left visual field, RH receives the information and then the information is transferred through the corpus callosum to the left hemisphere (LH). Usually the stimulus presentation time does not (and should not) exceed the magic number of 200 ms which is a threshold of attention shift (Posner & Raichle, 1999) and/or a time of initiating saccades when an eye is at rest (Springer & Deytsch, 2001). Thus, even if an eye movement occurs, the stimulus has already disappeared.

It should be noted, however, that in the research on normal subjects the information inevitably passes from one hemisphere to another so that the interhemispheric interaction occurs. Two of the most influential and widely used in experimental research models of hemispheric processing are of Zaidel et al. (1996) which are discussed in the next section.

### 4.2. Direct Access and Callosal Relay Models

The underlying base of the theory (Zaidel et al, 1996) is that both hemispheres are complete cognitive systems that are able to process information though using different strategies and resources. Thus, in a sense, the hemispheres are partially independent, processing information at different levels, although they work in parallel, interact with each other and complement each other. The authors state that hemispheric differences may occur at any processing stage and that the absence of hemispheric differences does not necessarily mean interactive processing, instead, it could mean "independent but similar processing in each hemisphere or different processes that yield the same results" (Zaidel et al., 1996; p.77). Dependency on the stage on which control process occurs (early sensory, in the middle of processing or prior to the task completion) may result in different types of hemispheric isolation from the whole process.

Two limit types of processing are reflected in the so-called "direct access" and "callosal relay" models. The "direct access" model assumes that each hemisphere is capable of linguistic processing independently of each other but with different degrees of efficiency. "Callosal relay" model assumes callosal transfer of the information from incompetent to a competent hemisphere prior to a high-level processing. Usually, a lateralized lexical decision or a kind of categorization tasks are used in order to verify the models. The main assumption is that if to pair each visual field with a response hand then the models are testable, taking into account the time that is required for callosal transfer of the motor command. Thus, if the LH is language-specialized then the "callosal relay" model predicts faster response with the right hand for both visual fields (i.e., independently of visual field) than with the left hand. The "direct access" model predicts faster response either with ipsilateral or with contralateral hands in each visual field. The logic with ipsilateral advantage is simple, within the framework of the "callosal relay" model logic. That is, if both hemispheres are able to independent processing than the right hand response would be faster than the left hand in right visual field presentation, and the left hand would be faster in the left visual field presentation. In the case of contralateral response advantage, however, since central decision processes could interfere with the response within each hemisphere, contralateral hand advantage may be shown as a result of this interference.

More simplified and more controversial way of verifying the models is a lateralized task (lexical decision or another one) without pairing visual field with the response hand. The criterion of "direct access" would be an interaction of visual field with some independent variable(s). In addition, such an interaction may show (different) processing strategies in the two hemispheres while an interaction between visual field and response hands may show processing resources in each hemisphere.

However, as Zaidel et al. (1996) points out, "the signal that mediates the hand-visual field coordination in choice RT tasks is abstract rather than sensory or motor" (p.81). To my opinion, this and also the fact of interhemispheric interaction in (especially) normals (it is hard to believe that, while one hemisphere is working, another is sleeping) posits a problem. The problem is that even if we get significant classical interactions we do not know how each hemisphere contributes to the overall process, especially if to believe that the two hemispheres are working in an ensemble, as an integrative whole. Moreover, as it was noted before, in any "linguistic" processing other "non-linguistic" processes (memory, attention, perception, decision-making in a simple lexical decision task, etc.) also take a part. The point is that to associate visual field (VF) of stimuli presentation with hemispheric processing may be not quite correct especially when one is working with normal subjects. Though initially the stimulus is presented to just one hemisphere and, possibly, "triggers" the process in that hemisphere, but then the information is passed through the corpus callosum to the other hemisphere and I suspect that we have little knowledge of what is going on after that.

## 4.3. Single Visual Word Processing

In the domain of lateralized visual field study there is a convention to associate VF with a corresponding hemisphere. In the review section I will keep this convention though I am not quite agree with it.

As it was noted before, research in the field (mainly) studies the possibility of accessing semantic system(s) by different hemispheres and the role of factors that are or may be involved in the process. Typically this kind of research employs visually lateralized lexical decision or categorization tasks. The data analysis is based usually on analysis of variance (ANOVA); in particular, an interaction between VF and some variables may show hemispheric strategies (within or across hemispheres) in linguistic processing in terms of RT and / or accuracy. The independent variables are predominantly word frequency, length, imageability and concreteness. However, the bulk of research either does not take into account grammatical class distinctions or describes stimuli as "words" without specifying their grammatical class (e.g., Boles, 1983; Hardyck et al., 1985; Iacoboni & Zaidel, 1996; Koenig et al., 1992; Rastatter et al., 1987; Scott & Hellige, 1998) which may represent a potential confounding variable. Sometimes, even if the researchers clearly state that they use only nouns, in fact, they are not controlling neither for grammatical class nor for morphological complexity (e.g., in Coney, 2002; *green, lovely, tears*). This grammatical class distinction is becoming increasingly important in research on lexical access, especially in relation to neurological studies which suggest that different neural systems may play a critical role in the production and comprehension of nouns and verbs (e.g., Damasio & Tranel, 1993; Daniele et al., 1994; Gainotti et al., 1995) as well as electrophysiological studies suggesting that nouns and verbs have distinct neural generators in the intact brain (e.g., Koenig & Lehmann, 1996; Pulvermüller et al., 1999). However, a number of recent studies directly addressed hemispheric asymmetry in the processing of different grammatical classes with a number of characteristics using lexical decision and/or categorization tasks. Hernandez et al. (1992) studied hemispheric capacities for the processing of adjectives and verbs with a lexical decision task. Their stimuli were chosen to be of high frequency and of medium imageability. Arguably, based on the absence of significant interaction between VF and grammatical class, the authors concluded that the results support the left hemisphere superiority for the processing of adjectives and verbs. Sereno (1999) examined hemispheric differences in noun and verb processing using lexical decision and noun/verb categorization task. Stimuli length was controlled, and frequency was manipulated. In addition, concreteness and imageability were used as covariates in the analysis. The analysis in the two experiments revealed grammatical class by VF interactions that showed no lateralization in noun processing and a left hemisphere advantage for verb processing. The results favoured the hypothesis that nouns and verbs are processed differently and by widely distributed brain structures. Nieto et al. (1999) also explored brain asymmetry for the processing of nouns and verbs. A lexical decision task was used. Frequency of the words was controlled and imageability was manipulated. The results showed no hemispheric differences in the processing of high and medium imagery nouns and of high imagery verbs and a left hemisphere advantage in the processing of low imagery nouns and medium and low imagery verbs. Thus, these studies suggest that more lateralization exists for verbs than for nouns and that lateralization depends on word properties, and especially on their imageability.

In most research on hemispheric asymmetries it is not overt naming but lexical decision or categorization tasks that are used. The main reason for this appears to be an attempt to "equalize" the output of both hemispheres since the LH is thought to be necessarily involved in articulation process. So, even if a word may be processed by the RH, overt naming would require LH participation, hence, RH would less likely manifest its capacities. Though, as Chiarello (1991) points out, it is still not clear when the LH takes its part in this process, although "some findings suggest that this occurs very late" (p.255). Lateralized studies with the word naming task have produced controversial findings concerning word frequency and imageability: earlier research (Boles, 1983; Lambert & Beaumont, 1983) showed that frequency affected number of errors in word recognition in both hemispheres, whereas imageability did not, though later research observed no frequency effect on lateralization (Scott & Hellige, 1998). Six experiments by Young & Ellis (1985) showed that length in letters affected the number of errors made in the right but not in the left VF. The length effect was constant for both low and high frequency levels of highly imageable nouns. It should be noted also that Iacoboni & Zaidel (1996) revealed a word length (measured in letters) influence in the left but not right VF using a lexical decision task. The effect was with respect to percentage of errors.

In studies that used the lateralized word naming task either only accuracy was taken as a dependent variable (Boles, 1983; Lambert & Beaumont, 1983; Young & Ellis, 1985) or stimuli were not controlled for grammatical class (Boles, 1983; Scott & Hellige, 1998; Coney, 2002). Thus, the present study may contribute to the existing behaviour research body by examining VF differences in the processing of grammatically unambiguous nouns, verbs and verb-derived nouns with different properties using a word naming task.

### 4.4. Picture Processing

Surprisingly, research with normal subjects is quite scarce. In the field, studies may be devoted to a "number of semantic memory systems", to peculiarities of perceptual processing in the two hemispheres and to semantic capabilities and recognition capacities of different categories of each hemisphere (e.g., Zaidel, 1994; Marsolek, 1999; Nieto et al., 1990; McAuliffe, & Knowlton, 2001). Usually, the task is to categorize or to name a picture. Again, the use of different experimental paradigms and manipulations brings to contradictory results, for instance, while a categorization task brought to the absence of VF differences in RT and task accuracy (Nieto et al., 1990), a rapid visual presentation with different stimulus-onset asynchronies of normal oriented and inverted objects and an identification and eventually naming task (McAuliffe & Knowlton, 2001) showed shorter identification times in left VF. Thus, while one study states that the RH is specialized for object identification, another, based on the accuracy measure, claims that RH could make category judgements tasks. Zaidel (1994) found left VF RT advantage for typical than for atypical members of a category and no RT difference in between these exemplars in the right VF. The author suggested that RH may be specialized in the processing of standard and/or stereotypical concepts.

Notably, only Nieto et al. (1990) reported control for the stimuli typicality and imageability and Zaidel (1994) controlled typicality levels. The other studies (Marsolek, 1999; McAuliffe & Knowlton, 2001) had no control of either response word or picture characteristics. Although the aim of the studies was different than to trace response word and picture characteristics influence on the processing, it seems that a complete neglect of these characteristics may pose a question of the validity of the results.

Liégeois & Schonen (2002) studied children performance (from 2 to 6-year old) using picture stimuli taken from popular books and cartoons thus, in such a way the frequency and familiarity of words and objects were controlled. Based on the obtained accuracy of naming, the authors concluded that the interhemispheric interchange occurred not only on visual but also on lexico-semantic levels even for the two-year old children.

Taking into account an absence, to the best of my knowledge, of a comparative study of picture naming with different response word characteristics, including grammatical, in the experimental paradigm of divided visual field, the study may contribute to the field exploring the VF latency differences in a production-like task where perceptual and conceptual characteristics play, possibly, a major role in the processing.

### 4.5. Neuroimaging Studies of Word and Picture Processing

Only a few studies examined hemispheric differences in word processing with a use of neuroimaging technique. Some of them (e.g., Rutten et al, 2002; Doyle & Rugg, 1998) focus on rather methodology than the processing *per se*. Others (e.g., Federmeier & Kutas, 1999; Federmeier & Kutas, 2002) study ERP differences in processing of words and pictures within a context. A little bit better the situation is with picture naming. While some researchers use emotional picture stimuli to investigate hemispheric knowledge structure and the unconscious-conscious processing modes of sensory systems (Zaidel et al., 1995), others, using a priming technique, try to differentiate between perceptual and conceptual priming and to determine associated with the processes areas. For example, Lebreton et al. (2001) in a PET study revealed that the two different forms of priming may be subserved by different systems. They suggested that extrastriate cortex may be involved in processing of general perceptual aspects and that conceptual type of priming may be subserved by structures in left occipito-temporal and left frontal lobes. The authors used simple line drawings of living/nonliving objects, the stimuli were controlled for the name agreement only.

Finally, a study by Salmelin et al. (1994) used pure lateralized picture naming task. The stimuli were presented for 100 ms, the task was either passive viewing, or overt / covert naming. MRI images were taken in three time intervals: 0-200 ms, 200-400 ms, and 400-600 ms from the picture onset. The results show that the earliest activation occurs in the occipital cortex contralateral to the field of presentation. In the second time interval, occipito-parieto-temporal regions of both hemispheres, independently of VF, become activated. In the third time interval, the activation transferred to the frontal lobes of both hemispheres. The activation dynamics was the same for the three tasks but with the most active and widespread in the overt naming task. Thus, it seems that both hemispheres were actively involved in the process, moreover, the process patterns implied similarity in the three tasks. The authors note, however, that the activation patterns were different for all 6 subjects, yet the left-site sides become activated earlier in the overt naming condition in all subjects.

Thus, it seems that the study showed that the process started in the occipital area contralateral to the VF presentation and then both hemispheres become activated and took a part in the process.

### 4.6. Conclusion and Aims of Present Study

Overall, though it seems that a large research body exists in the field of lateralized visual word processing in terms of its latency and accuracy, lateralized picture processing and especially neuroimaging studies are quite scarce.

The main aim of the present study is to explore visual field differences in word naming and picture naming tasks, both behaviourally and using EEG technique. The same lexical items will be used for both tasks, which may give a possibility to trace more carefully the differences and similarities in the two divergent presentation modalities (visual word and picture). Moreover, the influence of some word characteristics on the process also will be studied. The stimuli will be unambiguous nouns, verbs and verb-derived nouns in Bulgarian. Verb-derived noun in Bulgarian is formed by adding a bound/derivational morpheme to the root of a verb. Verb-derived nouns are of a special interest because grammatically and morphologically they are considered nouns but semantically they include action (action semantics)*. Thus, it may be hypothesized that verb-derived nouns by their semantic weight are closer to verbs, and by their grammatical weight -- closer to nouns. So, verb-derived nouns represent a kind of ambiguity between their grammatical class and semantics hence, their processing could be more complex than that of unambiguous nouns and verbs which would be correspondingly reflected in RT. That is, naming RT will be slower for verb-derived nouns than for verbs and nouns. What characteristics will be more pronounced in the two different tasks? Probably, in word naming task verb-derived nouns will be closer to nouns and in the picture naming task, where conceptual information is more important, they will behave closer to verbs. As to the noun/verb difference, there are two possible accounts why verbs are, probably, cognitively more complex linguistic units. First, in Bulgarian, verbs bear morphological information (number, person and sometimes gender, in its passive forms). Second, verbs play a critical role in the sentence structure. Some developmental evidence suggests that verbs are learned later than nouns because of their greater conceptual complexity as compared to nouns (Colombo & Burani, 2002). All of this may make verbs harder to process even in isolation, than nouns. Noun stimuli will be one-morpheme words, singular, and carry only a gender morphological marker (Bulgarian has three genders, as all Slavic languages). Concerning VF differences, I expect to find right visual field advantage as in almost all VF studies on word processing with a horizontal presentation, and probably no VF differences in picture naming study. How word characteristics will influence RT? Bulgarian is more or less orthographically transparent language so, probably, semantic characteristics (e.g., imageability) would affect word processing in low but not high frequency condition. Picture processing would be influenced more (and mostly) by name agreement and then by more conceptual characteristics of the response word than by their length and/or frequency. It is also possible that in some situations such word characteristics as imageability or length in word processing will be more important than its grammatical properties. Recall that Bird et al. (2001) obtained a null effect of grammatical class when imageability was controlled.

As electrophysiological measure of processing the gamma-band oscillations will be used. Gamma-band was shown to be related to cognition and language processing. I will talk about gamma-band in a separate section. I expect to find activation in occipital lobes in noun processing and especially in object naming task. Verbs and action naming may activate more motor areas, following the results and the logic of Pulvermüller et al. (1996; 1999). Electrophysiological correlates may appear to be sensitive to verb-derived nouns so, probably, if the "action semantics" is strong enough, this would be reflected in the activation in/or close to motor areas. How will word characteristics influence gamma activation? The results of literature overview puzzle: from one side, left frontal lobe is involved in orthography-to-phonology transformation, from another -- it is involved in semantic processing, as well as temporal lobes which simultaneously participate in phonological retrieval, an so on. At this point, I am afraid, I can say nothing. Also, take into account that none of the presented studies used gamma-band in a lateralized task. It is not clear how gamma would react and reflect these word properties, if it generally would. Thus, it is rather an explorative study on gamma oscillations and their sensitivity to different word properties and general relation to language processing in two lateralized tasks. Therefore, the main focus will be not on associated with stages/processes areas but on gamma behaviour and sensitivity.

* Some linguists refer verb-derived nouns to both grammatical classes, to nouns and to verbs (e.g., Stojanov, 1980). For convenience, I will refer to verb-derived nouns as to a separate grammatical class although their status is ambiguous and they are not representing a separate grammatical class.

# CHAPTER 5. EXPERIMENT 1. WORD NAMING: REACTION TIME STUDY

## 5.1. Method

### 5.1.1. Subjects

Overall, 120 subjects participated in the experiments. 60 subjects (28 males and 32 females) participated in noun and verb naming tasks and 60 (30 males and 30 females) in verb-derived noun naming task. All were university students with an average age of 21.7 years (range 18 - 33) and right-handed Bulgarian monolinguals with normal or corrected to normal vision. Participants received course credit or were paid for the participation.

### 5.1.2. Stimuli and Design

First, 60 nouns and 60 verbs were selected from the dominant responses in an on-line picture naming task (Object and Action naming, 520 and 275 pictures, respectively) which is part of a cross-linguistic norming study (Bates et al., 2000). 50 subjects (university students) participated in each of these experiments. The dominant response to a picture would be the name produced by the highest number of subjects. Subjective frequency ratings on a scale from 1 to 7 (1 – lowest word frequency) were collected for the dominant responses from 40 university students in order to compensate for the lack of reliable objective frequency counts in Bulgarian.

The roots of the selected 60 verbs were used to form verb-derived nouns. In Bulgarian, verb-derived noun is formed by adding a 2-letter/1-syllable bound/derivational morpheme to the post-position of the verb root. The results of a subjective frequency post-test allowed to use 3 frequency levels: high (19 items), medium (22 items), and low (19 items). T-test revealed significant differences across the combinations (for the characteristics of the selected word stimuli see Table 1). All selected for the experiment word stimuli are presented in the Appendix 1.

The word stimuli (targets) for the noun and verb naming tasks consisted of 20 nouns and 20 verbs for each of the three frequency groups: low, medium, and high. Actions were named with verbs in their citation form in Bulgarian which is in the present tense, first person, singular. Nouns and verbs were matched for length (in letters and syllables) and frequency as much as possible. None of the words started with a fricative. Words were mostly of four, five, or six letters long with 3 exceptions (2 nouns and 7 verbs were 3-letter long, and 1 verb was 7-letter long). Length measured both in number of letters (which correspond to phonemes to a

Table 1: Means and SDs of target word characteristics

| | | Mean (SD) | Low M(SD) | Medi M(SD) | High M(SD) |
|---|---|---|---|---|---|
| N | Letters | 4.8(0.8) | | | |
| O | Syllb | 2.1(0.2) | | | |
| U | Freq | 4.1(1.2) | 2.8(0.4) | 4.1(0.3) | 5.5(0.5) |
| N | Image | 5.9(0.6) | 5.5(0.6) | | 6.3(0.2) |
| | Concr | 6.0(0.5) | | | |
| V | Letters | 4.5(0.9) | | | |
| E | Syllb | 2.1(0.2) | | | |
| R | Freq | 4.1(1.2) | 2.7(0.5) | 4.1(0.3) | 5.5(0.5) |
| B | Image | 4.7(0.8) | 4.1(0.5) | | 5.3(0.4) |
| | Concr | 4.6(0.6) | | | |
| V | Letters | 6.3(0.7) | | | |
| D | Syllb | 3.1(0.2) | | | |
| N | Freq | 4.5(1.1) | 3.2(0.6) | 4.5(0.3) | 5.7(0.5) |
| | Image | 5.6(0.8) | 5.0(0.7) | | 6.2(0.3) |
| | Concr | 4.4(0.5) | | | |

greater extent in Bulgarian than in English) and number of syllables as well as means and standard deviations for frequency ratings for the selected nouns and verbs are shown in Table 1. A *t*-test revealed no significant difference in the mean length of verbs and nouns measured in letters or syllables. Naturally, verb-derived nouns appeared to be longer in letters and syllables than nouns and verbs. T-test revealed significant difference in the mean length in letters/syllables of verb-derived nouns and verbs and nouns.

Imageability ratings for the selected stimuli were collected using the procedure and instruction published in Paivio, Yuille, and Madigan (1968), on a seven-point scale (1 – lowest imageability). For this purpose, 40 university students were asked to rate words depending on the ease/difficulty with which these words arouse mental images. As a result of the post-test, stimuli were subdivided into two levels of imageability, low and high (cf. Table 1). A *t*-test revealed significant differences across all the combinations of the two levels of imageability and grammatical class except for that between nouns of low imageability (5.5) and verbs of high imageability (5.3), between nouns of high imageability (6.3) and verb-derived nouns of high imageability (6.2), and between verbs of high imageability (5.3) and verb-derived nouns of low imageability (5.0). In addition, concreteness ratings were also obtained from 40 university students using a seven-point scale (1 – most abstract) as shown in Table 1. A *t*-test showed that nouns received significantly higher ratings for concreteness than verbs and verb-derived nouns. Thus, imageability and concreteness could not be balanced across frequency levels.

Stimuli were presented unilaterally in capital letters on a Macintosh computer. The fixation point was a cross ("+") in the center of screen. Stimuli were presented horizontally and placed to the right or to the left of the fixation point. The distance to the center of the stimuli subtended a horizontal visual angle of 4 degrees in relation to the subject. The average visual angle from the fixation point to the nearest edge was 2.8 degrees for verbs, 2.7 -- for nouns, and 2.6 -- for verb-derived nouns. The distance between the subject's head and the screen was kept 60 cm.

Finally, the independent variables were Visual field (Left and Right VF), Word Frequency (Low, Medium, and High), Imageability (Low, High), and Grammatical Class (Noun, Verb, Verb-Derived Noun) with reaction times (RTs) and errors as dependent measures. Concreteness of words and length of verb-derived nouns were not included in the variables. Trials on which words were named differently from the target were considered as naming errors and were not analysed as such.

### 5.1.3. Procedure

Subjects were tested in a sound proof room. Six randomized orders for each grammatical class were constructed. The experiment consisted from two main parts: (1) noun and verb naming, and (2) verb-derived noun (VDN) naming. Each subject participated in part 1 was run on the noun and verb conditions in separate sessions. None of the subjects participated in part 2 (VDN naming) was run in part 1 (noun and verb naming). The sessions started with 13 practice trials. The appearance of the stimuli in each visual field and the order in which the sessions were presented were counterbalanced across subjects. Each stimulus was presented only once to each subject – either in the left (LVF) or in the right visual field (RVF). Each stimulus was displayed for 200 msec. Immediately after that a mask (randomly distributed black lines and curves on a white background) was displayed at the same place as the stimulus for 200 msec. Subjects were instructed to name the word on the screen as fast and as accurately as possible without moving their gaze from the fixation point. The intertrial interval was chosen to vary randomly between 1 and 2 sec and time-out was 5 sec (i.e., if the subject produced no response, the next trial started in 5 sec). Reaction time was measured from the offset of each stimulus. Naming errors were recorded by the experimenter. The importance of maintaining one's gaze on the fixation point was repeatedly stressed. Each session lasted approximately 7–8 min. Subjects had a 5-min break between the two sessions in part 1 of the experiment. A Power Macintosh 6400/200 equipped with the PsyScope software controlled stimuli presentation and timing.

## 5.2. Results and Discussion

### 5.2.1. Data Reduction

Trials on which no response was registered (9.2% for part 1 and 10.6% for part 2) and trials with technical errors (1.3% for part 1 and 0.9% for part 2) were excluded from the analyses. Upon examination of the data distribution, responses with RTs longer than 2 s (0.7% for part 1 and 1.4% for part 2) were excluded from the analysis as outliers. The data were averaged by items over subjects. Only correct responses were included in the RT analysis. Thus, a total of 78.5% (part1) and 70% (part 2) of the originally collected RT data was included in further analyses.

### 5.2.2. Analysis of variance of VF by Grammatical Class by Word characteristics

A VF x Grammatical class x Imageability x Frequency analysis on RT obtained significant main effects for all four independent variables. There was a significant main effect of VF ($F_{(1,324)}=17.88$; $p=0.00$); word naming took longer when a word was presented in the LVF (mean RT=755 ms) than when it was presented in the RVF (mean RT=731 ms). This RVF advantage is a typical main effect in lateralization studies employing word stimuli. Probably, one of the most important reasons lies in the way of stimuli presentation. Stimuli are presented horizontally so, in RVF presentation the beginning of a word is seen better, hence, it is better recognized and is read and processed faster/easier. In LVF presentation, however, the ending of a word is seen better which makes the word harder recognizable and harder to process.

A significant main effect of Grammatical class ($F_{(2,324)}=53.59$; $p=0.00$) showed that verbs were named significantly faster (mean RT=712 ms) than nouns (mean RT=734 ms) and nouns were named significantly faster than verb-derived nouns (mean RT=782 ms). Additional analysis showed that the effect was not due to the length of the verbs (which were slightly shorter than nouns in mean length – 4.52 vs. 4.75 letters). One possible explanation may be in the way the stimuli were presented, i.e., separate sessions for nouns and verbs. In Bulgarian, verbs (unlike nouns) have a rich inflectional system that marks tense, number, person, mood, and sometimes gender. All verbs were in their citation form which is the present tense, first person, singular. Since they were presented in a separate block, subjects could have been morphologically primed so that the root (in the beginning of the verbform) was sufficient to read the whole verbform as the ending was highly predictable. The ending of VDN was also highly predictable but here, it seems length and, possibly, other factors slowed down RT.

A significant main effect of imageability ($F_{(1,324)}=7.66$; $p<0.01$) showed that words with high imageability were named faster (mean RT=735 ms) than those with low imageability (mean RT=751 ms).

A significant main effect of frequency also was obtained ($F_{(2,324)}=16.37$; $p<0.00$). High frequency words were named faster (mean RT=726 ms) than medium frequency words (mean RT=737 ms), which in turn were named faster than low frequency words (mean RT=765 ms). A post hoc analysis revealed significant differences between high and low frequency words and low and medium frequency words in mean reaction times. The difference between high and medium frequency words was not significant.

No significant interactions were found. It seems, that ANOVA was not sensitive enough to reveal the interdependence of VF and word characteristics in the task. In order to determine whether concreteness

Table 2: Correlations among word characteristics for each grammatical class.

| | | Letter | Freq | Image |
|---|---|---|---|---|
| Noun | Freq | n.s. | -- | |
| | Image | n.s. | 0.59*** | -- |
| | Concr | -0.27* | n.s. | 0.31* |
| Verb | Freq | n.s. | -- | |
| | Image | n.s. | 0.55*** | -- |
| | Concr | n.s. | n.s. | 0.44*** |
| VDN | Freq | n.s. | -- | |
| | Image | n.s. | 0.29* | -- |
| | Concr | n.s. | n.s. | 0.40** |

*** -- $p<0.001$; ** -- $p<0.01$; * -- $p<0.05$; n.s. -- non-significant and/or length affected the present results, an ANCOVA was conducted with length and/or concreteness as covariates. The analysis revealed that neither concreteness nor length influenced the ANOVA results.

### 5.2.3. Conclusion

From the results obtained it is clear that neither ANOVA nor ANCOVA were informative enough concerning behavior of word characteristics and VF differences. To understand better the role and independent contribution of every word characteristic to the errors and RT of each grammatical class in each visual field, correlation and stepwise multiple regression analyses were conducted. In the following sections the analyses for each grammatical class and visual field are presented.

### 5.2.4. Correlation Analysis among Word characteristics and RT

Correlation analyses were conducted over items to study the relationship between word characteristics separately for each grammatical class in each VF, and contribution of each word characteristic to noun, verb and VDN naming RTs and errors. Correlations among word attributes (length in letters, frequency, concreteness and imageability) separately for each grammatical class are presented in Table 2. Imageability was highly positively correlated with frequency and concreteness in all grammatical class conditions. It also appeared that concreteness correlated with length in letters in the case of nouns. Note that neither frequency nor imageability had such a correlation with letters. Thus, one implication of these results is that even if length was controlled in terms of a match across nouns and verbs, it may have been confounded with concreteness. No other significant correlations were found.

The correlations of imageability with these word attributes are not surprising. In order to reveal how each word characteristics influenced RT in the different VFs and grammatical classes, correlation analyses were conducted separately for each grammatical class presented in each VF. Table 3 summarizes the correlations between word characteristics and RTs.

As it is seen, the length of words correlated positively with RTs only in the case of nouns presented to the RVF ($r$ = .29). Thus, longer nouns presented to the RVF were named slower than shorter nouns. Note that no such sensitivity to length was observed for either the nouns presented to the LVF, or the verbs and VDNs in both VFs. Frequency correlated negatively with RTs in all conditions except for VDN naming in LVF; typically and as expected, more frequent words were named faster. Imageability correlated with RTs

Table 3: Correlations between word characteristics and RTs separately for each VF and grammatical class.

| VF | Word | Length | Freq | Image | Concr |
|---|---|---|---|---|---|
| R | Noun | 0.29* | -0.37** | -0.28* | n.s. |
| | Verb | n.s. | -0.51*** | -0.32** | n.s. |
| | VDN | n.s. | -0.31* | n.s. | n.s. |
| L | Noun | n.s. | -0.46*** | -0.60*** | n.s. |
| | Verb | n.s. | -0.35** | -0.48*** | n.s. |
| | VDN | n.s. | n.s. | n.s. | n.s. |

*** -- p<0.001; ** -- p<0.01; * -- p<0.05; n.s. -- non-significant

Table 4: Unique contributions to RT of each predictor when entered on the last step and partial correlations, separately for each grammatical class and VF

| | | Noun | | Verb | | VDN | |
|---|---|---|---|---|---|---|---|
| VF | Predictor | % Var | r= | % Var | r= | % Var | r= |
| R | Length | 9.5 | 0.33* | 5.03 | 0.26* | 6.0 | 0.25~ |
| | Freq | 6.0 | -0.27* | 18.4 | -0.46*** | 9.8 | -0.32* |
| | Image | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| | Concr | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| L | Length | n.s. | n.s. | 5.3 | 0.26* | n.s. | n.s. |
| | Freq | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| | Image | 18.2 | -0.49*** | 8.9 | -0.34* | n.s. | n.s. |
| | Concr | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |

*** -- p<0.001; ** -- p<0.01; * -- p<0.05; ~ -- p<0.06; n.s. -- non-significant again in all conditions except VDN presented in both VFs. It seems that in the processing of nouns and verbs, imageability was a more important characteristic in LVF presentation processing mode than in the right one and it did not play any role in the processing of VDNs. Concreteness, however, did not correlate with RT in either condition.

To summarize, the results suggest that frequency and imageability facilitated processing (decreased RTs) in both VFs for nouns and verbs while length slowed down the response times only when nouns were presented in the RVF. However, for VDNs only frequency facilitated processing only in RVF. It appeared that concreteness had no effect in either condition.

### 5.2.5. Regression Analysis with Predictors/Word Characteristics as Variables

In order to reveal further the influence / contribution of each word characteristics in all conditions (grammatical class and VF), a stepwise multiple regression was performed with each predictor (word characteristics) entered in the equation last to determine its unique contribution to RTs when all other predictors were controlled on the first step. Table 4 presents the results of the stepwise regression on RT for each grammatical class and VF separately. The results showed no imageability contribution to RTs in the RVF and no frequency contribution to RTs in the LVF for either grammatical class. Thus, even though word frequency and imageability were highly correlated (Table 2), the regression analysis revealed a dissociation which promised to clarify better the independent role played by each of these predictors. It appears that VF processing of the three grammatical classes benefited from different strategies, a result that was not obvious in the correlation analysis (Table 3). Concreteness, however, did not make any contribution to either VF response times.

Frequency and length in letters were important for word processing in the RVF, and imageability in the LVF for nouns and verbs. Note, that the analysis revealed also a "hidden" factor – length contribution in the variance of RT when verbs were presented to both VFs, a result that was not present in the raw correlations (Table 3). In order to reveal whether this length contribution in the LVF presentation condition was due to the length variance or some other factors, an additional analysis was conducted. From the analysis were excluded those verb items which had "outlier" length, i.e., 7 3-letter items and 1 7-letter item. The regression analysis showed the same pattern (cf. Table 4) excluding length contribution to the RT variance in LVF condition. Thus, variance in the length of verbs influenced behavior in LVF but did not in the RVF. The result that concreteness did not influence RT in either condition may be explained by the relative homogeneity of the stimuli in this respect since their selection was made from the dominant responses of picture naming experiments where most targets were highly picturable. VDN processing in LVF was not influenced by any of the predictors.

Overall, the results indicated that different types of information sources were activated when words were presented to the different visual fields. Noun, verb and VDN processing was influenced by length and frequency in the RVF and by imageability of nouns and verbs in the LVF; in the case of verbs, length also made its unique contribution to RTs. VDN processing in LVF was not influenced by either predictor which confirmed the results of correlation analysis (cf. Table 3).

### 5.3. Conclusion

The results of ANOVA demonstrated that, contrary to the expectations, verbs were processed faster/easier than nouns. This result was attributed to a kind of a morphological priming effect. Thus, the overall experimental context (separate presentation sessions of grammatical classes) could influence verb processing advantage over noun processing. It might be hypothesized that in a mixed type of presentation the effect would disappear. Some support for this hypothesis was found in other studies. For instance, Sereno (1999) obtained a main effect of grammatical class on RT which showed nouns advantage over verbs in a mixed stimuli presentation with lexical decision and a noun/verb categorization tasks. However, in a study by Nieto et al. (1999) no main effect of grammatical class was observed with a lexical decision task. Note that the study was done in Spanish where verbs have rich morphology with inflexions that mark the tense, number, and person. Nieto et al. (1999) did not report the verb form, presumably, they were presented in an infinitive that is, without informative inflexions. Furthermore, the stimuli were presented in separate blocks as in the present experiment. This comparative analysis suggests that, indeed, the way of presentation may influence the processing mode. Some support comes also from a study of Chiarello et al. (2000) that noted that VF x Grammatical class interactions were more reliably obtained with mixed lists than with blocked. Future studies are needed to understand better the influence of experimental context on word processing.

The results of ANOVA indicated that VDNs were processed slower than the two other grammatical classes which is in agreement with the expectations. Probably, their ambiguous properties along with the considerably longer in characters length influenced the processing time.

The results also demonstrated that with an overt naming which is "a process clearly lateralized to the LH" (Nieto et al., 1999; p.430) it is still possible to explore VF differences applying correlation and especially multiple regression analyses in addition to the ANOVA. Though no significant VF x independent variable interaction was obtained, the multiple regression analysis showed differential strategies/patterns that were prompted by stimuli presentation to different VFs. The strategies were clearly dependent on different word characteristics. It should be noted, however, that on the basis of regression analysis it is not possible to speak of 'strategies' in terms of presence or absence of VF advantages/efficiency in the processing of some levels of variables over others (or, in terms of time course, for that matter). Instead, it is possible to view the brain strategies that depend on the VF presentation, as the activation of information sources necessary for the processing of a given grammatical class with certain word characteristics. It may be assumed that the stimuli initial presentation to the RVF (LH) "triggered" more verbal/linguistics properties to be involved in the overall processing, and the initial stimuli presentation to the LVF (RH) "triggered" more non-linguistics properties, i.e., imageability, in the case of verbs and nouns. VDN processing in this condition, probably, was influenced by other factors that were not explicitly taken into account (i.e., the dissociation between grammatical class and semantic content). In addition, length of VDN could also have its confounding contribution to the complex processing. Since subjects have seen the ending (i.e., the bound morpheme) of a word better than the beginning (i.e., the verb root) when the word was presented to the LVF, the word was harder to recognize hence, harder to process. In support of the assumption of length influence on the LVF processing of VDN could be taken the result of RVF processing. In RVF (LH) presentation the root of VDN was seen better and its processing was not different from processing of the two other grammatical classes, i.e., more verbal properties were activated with the RVF (LH) presentation.

Continuing this line and taking into account traditional hemispheric role assignments like LH is more analytical/sequential while RH is more holistic/parallel in processing it could be suggested that the findings may be interpreted as being in favor of the dual coding theory (Paivio, 1990; 1991). Dual coding theory (DCT) differentiates verbal (logogens) and nonverbal (imagens) systems assuming within- and between-system relationship. Different kinds of processes underlie the two systems: while the verbal system is specialized for sequential processing, the nonverbal system is characterized by synchronous processing. It may be that the verbal system is more associated with LH functions and the nonverbal one -- with the RH, although, of course, this does not imply a strict system-based hemispheric separation or localization.

Paivio (1991) showed that most experiments based on retrieval processes confirmed DCT. Bearing in mind that the word naming in the experiments was, in fact, a kind of short-term recall task (since the word stimuli disappeared from the screen before subjects could name them), it could be assumed that this short period of time was sufficient to activate either one or both systems. In the experiment, presentation of words of the three grammatical classes to the RVF (LH) highly activated the verbal system and presentation of nouns and verbs to the LVF (RH) activated the nonverbal system as reflected in RTs. However, larger dispersion in the length of verbs presented to the LVF (RH) activated both verbal and nonverbal systems. Thus, RH was able to activate either of two systems (verbal or nonverbal) that is, it may be premature to postulate the association of each hemisphere with an invariant function in lexical processing. On the other hand, recall that the exclusion of length outliers confirmed the RVF (LH) verbal system activation and cancelled the verb length contribution to the LVF RT. That is, when verb length was better controlled, no differences in the processing strategies of noun and verb were observed even though verb imageability was considerably lower than noun imageability. In addition, VDN presentation to the LVF (RH) did not activate either of considered information sources. So, it seems that the brain processing strategy is highly dependent on word characteristics and the range of their "internal" variability.

In conclusion, the experiment produced results demonstrating the role of word attributes in lateralized word naming processing. It also underscored the usefulness of other kinds of analysis in addition to ANOVA, especially in the word naming task which have been unduly neglected until now. Finally, the results suggested the existence of different processing strategies used by the brain that depend on the field of presentation and word characteristics.

The next section explores the impact of response word characteristics in a lateralized picture naming task.

## CHAPTER 6. EXPERIMENT 2. PICTURE NAMING: REACTION TIME STUDY

The initial intention was to compare two different tasks (word naming and picture naming) that produce the same lexical items. Pictures for the experiment were selected according to their dominant responses that were used in the experiment 1 (word naming) as word stimuli. The experiment was done but several problems occurred during and after the experiment completion. The problems were due to the lack of control of pictures visual complexity. Subjects rarely could recognize the pictures presented very rapidly and in a small size. The implication was that more attention has to be paid to perceptual characteristics of picture stimuli in a complex lateralized picture naming task. In an attempt to avoid to some extent these problems, another experiment was designed.

## 6.1. Method

### 6.1.1. Subjects

Overall, 120 subjects participated in the picture naming experiments. 60 subjects (28 males and 32 females) participated in object and action naming experiments and 60 subjects (30 males and 30 females) in object and VDN naming experiments. Subjects were university students with an average age of 22.03 years (ranged from 18 to 35). They were all right-handed Bulgarian monolinguals. None of them has participated in the previous picture naming experiments. All of them had normal or corrected to normal vision. Participants received course credit or were paid for the participation.

### 6.1.2. Stimuli and Design

140 pictures from object naming pool (520 pictures) and 136 pictures from action naming pool (275 pictures) were selected. Stimuli selection was based on consensus from picture naming norming study, image agreement (only for object naming) and the results of a kind of a recognition pre-test with shorter presentation time (150 ms) than in the actual experiment (200 ms). No length was taken into account (controlled) as well as presence of a fricative in the beginning of a word. The most important interconnected factors in the stimuli selection were comparatively low visual level of complexity and high level of recognition of a picture that were determined in a picture recognition pre-test with 150 ms presentation window (one subject with impaired vision). Having more than twice the number of stimuli (comparable to word naming task) I intended later on to select the data according to naming consensus and to do the justified in the word naming experiments correlation and multiple regression analyses. Moreover, this time the word class in the design was a within-subject variable, i.e., one part of the experiment was run with object and action naming, and another -- with object and verb-derived noun naming. The main reason for such a design was an attempt to trace subject factor and to have more data on object naming that is, to combine the object naming data from two experiments into one pool in a case of the same (tendency) results obtained out of the two experiments.

Action pictures were used for action and VDN picture naming. Mean consensus (SD) for dominant responses of the selected object pictures obtained from object naming norming study was 92% (5.6%), mean frequency -- 4.5 (1.0), mean imageability -- 6.23 (0.27), mean concreteness -- 6.0 (0.45), mean length in letters -- 5.5 (1.55), mean image agreement -- 5.8 (0.4). Mean consensus (SD) for dominant responses for action pictures obtained from action naming norming study was 55% (22%), mean frequency -- 4.5 (1,2), mean imageability -- 5.3 (0.7), mean concreteness -- 4.6 (0.53), mean length in letters -- 6.0 (2.2). We do not have a VDN picture naming norming study so, only VDN word characteristics are reported. Mean frequency (SD) for verb-derived nouns was 4.86 (0.97), mean imageability -- 5.5 (0.8), mean concreteness -- 4.5 (0.50), mean length in letters -- 7.2 (1.5).

Stimuli were back and white line drawings 4.5 x 4.5 cm presented unilaterally on a Macintosh computer. The fixation point was a cross ("+") in the center of screen. Stimuli were placed to the right or to the left of the fixation point. The distance to the center of the stimuli subtended a horizontal visual angle of 4 degrees in relation to the subject. The visual angle from the fixation point to the nearest edge was 1.9 degrees. The visual angle from the fixation point to the furthest edge was 6.18 degrees. The distance between the subject's head and the screen was kept 60 cm.

For analysis of variance VF (LVF, RVF) x Grammatical class (Noun/object naming, Verb/action naming, VDN/VDN action naming) design was used. Dependent variable was RT of target response words. In correlation and regression analyses all response word and picture characteristics served as RT predictors separately for each VF and grammatical class.

### 6.1.3. Procedure

The procedure was the same as in Experiment 1 (Word naming). The differences were the following. Here time out was chosen to be 8 sec. Subject's responses were recorded by the experimenter. Each experiment consisted of two parts with two sessions each: object and action naming for one experiment, and object and VDN naming for another. The task was to name a picture in the object naming session (noun), to name a picture as an action (verb) in first person, singular, present tense in the action naming session, and to name a picture as a verb-derived noun (examples of VDN form were provided) in a VDN action naming session. Subjects were required to name the pictures as fast and accurate as possible. Each session started with 8 practice trials.

Each session lasted for approximately 30 min. Subjects had 3 breaks during each session.

## 6.2. Results and Discussion

### 6.2.1. Data Reduction

Since separate analysis of object naming data of the two sessions revealed the same pattern of results (both correlation and multiple regression analyses) the data were combined and are reported as such. Trials on which no response was registered in object naming consisted of 2.7% of data, technical and/or other errors consisted of 0.6% of data. After the revision of RT distribution 0.5% outliers were excluded from further analysis (RT>=4000ms). The analysis was done on mean RT ± 2SD, 4.6% of data was removed. The data were averaged over subjects by VF and word characteristics, and mean RT for each valid response was obtained. Out of these data dominant responses (i.e., the names used by most participants) in each VF were computed and selected for further analysis. Minimum accepted consensus value was chosen to be 33.3% (so that at least one third of the participants agreed on a picture name). The data that fell below the selected criterion were removed from the analysis. After a revision of dominant responses, all morphologically complex words (compounds) and dominant responses in plural form were also removed. As a result, for final analysis remained those dominant responses that were equal for particular pictures in both VFs and in both experimental sessions (125 object pictures for each VF). Table 5 presents means and SDs of characteristics of used dominant responses in object naming.

Data preparation of action and VDN naming was done in a similar fashion as of object naming. Subjects could not name a picture in 7.3% of cases in action naming task and in 8.5% in VDN naming task. Technical and/or other errors consisted of 0.6% in action naming and 0.9% in VDN naming. Upon examination of the data distribution, responses with RTs longer than 5 sec (1.4% in action naming and 1.8% in VDN naming) were excluded from the analysis. Then all data points that lied out of mean RT ± 2SD were removed from further analysis (5.3% in action naming and 5.2% in VDN naming). The remained data were averaged over subjects by VF and word characteristics. From the averaged file dominant responses along with their RTs were obtained. Here again, the minimum consensus of data acceptance was 33.3%. Besides, the data of a response in reflexive form were also removed so that only verbs in their citation form in Bulgarian which is in the present tense, first person, singular, remained for further analysis. Finally, for the analysis remained the data of those dominant responses (targets) that were equal as a response for a picture in both VFs (60 picture data of action naming and 62 of VDN naming for each VF). Of the accepted picture naming data 48 pictures appeared be common for the two, action and VDN naming. This difference partially may be explained by the fact that reflexive verbs form a canonical verb-derived noun, that is, reflexives were deleted from action naming targets but they formed a "normal" VDN and were left in the main data table. Table 5 presents means and SDs of the accepted dominant responses in each picture naming task. Dominant responses of selected for the analysis pictures along with some examples of the used pictures are presented in Appendix 2.

### 6.2.2. Analysis of variance of VF x Grammatical class

A VF (LVF, RVF) x Grammatical class (Noun, Verb, VDN) analysis on RT revealed no main effect of VF and/or interaction between VF and grammatical class. Thus, the analysis did not find processing VF differences in picture naming tasks. A significant main effect of grammatical class ($F_{(2,488)}=255.09$; $p=0.00$) was obtained. Object naming took significantly shorter (mean RT=916 ms) than action (mean RT=1213 ms) and VDN (mean RT=1247 ms) naming. The difference between mean RTs of action and VDN naming almost reached significance ($p<0.06$). This difference in the RTs may be due to several reasons. The first is the difference between perceptual/visual complexities in the two types of pictures. Pictures for object naming contain single, more or less easily recognized objects. Pictures for action/VDN naming are more complex since they have to depict an action. Moreover, frequently these pictures contain more than just one object since many actions often require not only an agent of the action but also an instrument. Sometimes a corresponding surrounding/context is also necessary to be included into an action picture to "show" an action. The second reason lies on operations of different cognitive complexity levels in different naming tasks. It seems that to name an object (say, a bird) is easier than to name a "flying" bird as an action/verb "to fly". That is, perceptually and conceptually, possibly, most important and salient information is that it is a bird (an object). Since the task required to name the picture as an action in the first person, singular, present tense, subjects should make an effort to "convert" the "moving" object into that verb form. Thus, possibly, several mental operations were required to complete the task. With VDN naming the situation seems to be even more complicated. Probably, this task required at least one step/operation more than in action naming. That is, to "convert" the object(s) into an action and then to "convert" the action into the VDN form. In addition, another possible reason of slow RTs in action and VDN naming tasks in comparison to RT in object naming is the difference in consensus (name agreement) in the tasks (cf. Table 5). Comparatively low consensus for action and VDN naming tasks reflects the possibility of eliciting a greater number of

Table 5: Means and SDs of dominant response characteristics for each VF and grammatical class

| VF | PN Type | RT, ms, M(SD) | Image Agr, M(SD) | Cons, %, M(SD) | Length, M(SD) | Freq, M(SD) | Image, M(SD) | Concr, M(SD) |
|---|---|---|---|---|---|---|---|---|
| R | Object | 917(124) | 5.8(0.4) | 86.3(13.3) | 5.3(1.3) | 4.5(1.0) | 6.2(0.3) | 6.0(0.5) |
| | Action | 1209(176) | -- | 58.2(17.5) | 5.4(1.8) | 4.8(1.2) | 5.4(0.7) | 4.7(0.5) |
| | VDN | 1258(182) | -- | 59.8(16.9) | 7.1(1.5) | 5.0(1.0) | 5.7(0.8) | 4.5(0.5) |
| L | Object | 915(108) | 5.8(0.4) | 88.8(10.8) | 5.3(1.3) | 4.5(1.0) | 6.2(0.3) | 6.0(0.5) |
| | Action | 1216(180) | -- | 61.3(16.7) | 5.4(1.8) | 4.8(1.2) | 5.4(0.7) | 4.7(0.5) |
| | VDN | 1237(207) | -- | 60.6(16.7) | 7.1(1.5) | 5.0(1.0) | 5.7(0.8) | 4.5(0.5) |

Table 6: Correlations among word characteristics (and image agreement for object naming only) for each grammatical class in PN task

| | | Letter | Freq | Image | Concr |
|---|---|---|---|---|---|
| Object | Freq | n.s. | -- | | |
| | Image | n.s. | 0.59*** | -- | |
| | Concr | -0.27* | n.s. | 0.31* | |
| | Image Agr | n.s. | -0.32*** | n.s. | n.s. |
| Action | Freq | -0.31* | -- | | |
| | Image | n.s. | 0.30* | -- | |
| | Concr | n.s. | n.s. | 0.33* | -- |
| VDN | Freq | n.s. | -- | | |
| | Image | n.s. | 0.29* | -- | |
| | Concr | n.s. | n.s. | 0.40** | -- |

*** -- $p<0.001$; ** -- $p<0.01$; * -- $p<0.05$; n.s. -- non-significant alternative names than for object naming. Competition between a number of activated related (synonyms) and sometimes even unrelated* concepts that depict an action inevitably slowed down RT.

However, in ANOVA none of the response word characteristics was taken into account. Correlation and multiple regression analyses may shed some additional light on the peculiarities of picture naming processing providing information about the impact of response word characteristics on RT in different conditions. Next sections are devoted to the correlation and multiple regression analyses.

### 6.2.3. Correlation Analysis among Response Word and Picture Characteristics and RT

As in word naming experiments, correlation analyses were conducted over items to study the relationship among word characteristics separately for each grammatical class, and between each word characteristics and naming RTs in each VF. Correlations among word (dominant response) attributes (length in letters, frequency, concreteness, and imageability) separately for each grammatical class are presented in Table 6. For object naming image agreement was also included in the analysis. Image agreement (a degree of picture-word mapping) correlated negatively only with frequency. So, less frequent words mapped with a picture better than highly frequent words. By Johnson et al. (1994), frequency may be not only a lexical characteristics but may contain also familiarity/and or accessibility of a concept. Continuing this line, less familiar (hence, more vague) concepts were mapped better with pictures, probably, because people's greater degree of uncertainty of how a concept looks like. From the other side, when subjects had clearer conception, it may often not map with a simple black and white drawing. Another explanation may be also possible. Low frequency items may be more 'unique' referentially (subordinate level) hence, more uniquely picturable. Thus, again, if subjects had clearer conception of these low frequency items, it did not map with simple drawing.

Note that not only length and concreteness but also imageability did not correlate with image agreement. Although imageability may have the same power of concept accessibility, it seems that for these items imageability ratings of dominant response and image agreement ratings were dissociable. That is, a degree of richness of sensory experience was not connected with the degree of picture-word mapping.

Imageability was highly positively correlated with frequency and concreteness in all grammatical class/picture naming types conditions. It also appeared that concreteness correlated with length in letters in the case of nouns (object naming) and frequency correlated with length in letters in the case of verbs (action

* for instance, a picture of a sitting/reading man may be named as "to seat", "to read", "to look", etc.

Table 7: Correlations between word characteristics and consensus separately for each VF and grammatical class in PN task.

| VF | PN type | Length | Freq | Image | Concr | Image Agreement |
|---|---|---|---|---|---|---|
| R | Object | $-0.20^{*}$ | n.s. | $0.25^{**}$ | $0.22^{*}$ | n.s. |
| | Action | n.s. | n.s. | $0.27^{*}$ | $0.25^{\sim}$ | -- |
| | VDN | n.s. | n.s. | n.s. | n.s. | -- |
| L | Object | $-0.17^{\sim}$ | n.s. | $0.25^{**}$ | $0.24^{**}$ | n.s. |
| | Action | n.s. | n.s. | n.s. | $0.27^{*}$ | -- |
| | VDN | n.s. | n.s. | n.s. | n.s. | -- |

$^{***}$ -- $p<0.001$; $^{**}$ -- $p<0.01$; $^{*}$ -- $p<0.05$; ~ -- $p<0.06$; n.s. -- non-significant

Table 8: Correlations between word characteristics, consensus and RT separately for each VF and grammatical class in PN task.

| VF | PN type | Consensus | Length | Freq | Image | Concr | ImAgr |
|---|---|---|---|---|---|---|---|
| R | Object | $-0.73^{***}$ | $0.26^{**}$ | $-0.34^{***}$ | $-0.35^{***}$ | $-0.22^{*}$ | n.s. |
| | Action | $-0.44^{***}$ | n.s. | n.s. | $-0.26^{*}$ | n.s. | -- |
| | VDN | $-0.31^{*}$ | n.s. | n.s. | $-0.34^{**}$ | $-0.37^{**}$ | -- |
| L | Object | $-0.70^{***}$ | $0.26^{**}$ | $-0.30^{**}$ | $-0.32^{***}$ | n.s. | n.s. |
| | Action | $-0.64^{***}$ | n.s. | n.s. | n.s. | $-0.40^{**}$ | -- |
| | VDN | $-0.41^{**}$ | n.s. | n.s. | n.s. | n.s. | -- |

$^{***}$ -- $p<0.001$; $^{**}$ -- $p<0.01$; $^{*}$ -- $p<0.05$; n.s. -- non-significant naming). Note, that in the case of VDN correlation between length in letters and any of the word characteristics was absent. No other significant correlations were found.

In order to reveal how consensus in picture naming was connected with response words characteristics, correlation analysis was done separately for each VF and grammatical class. Table 7 presents correlations between word characteristics and consensus separately for each VF and grammatical class. Image agreement was included as a picture characteristics for the object naming condition. Image agreement did not correlate with consensus which may reflect relative homogeneity in object pictures in terms of their comparatively high consensus and image agreement rating (cf. Table 5). Length correlated negatively with consensus only in the object naming task in both VFs. Frequency did not correlate with consensus in any condition. Imageability correlated positively with consensus in object naming task in both VFs, and in action naming it correlated only in RVF condition. Thus, seemingly close consensus data in VFs of action naming task (cf. Table 5) appeared to be influenced differently by imageability factor. Concreteness correlated in object and action naming tasks in both VFs conditions. Note, that none of the characteristics correlated with consensus in the case of VDN picture naming. Thus, consensus was mainly influenced by imageability and concreteness in object and action naming and length in the case of object naming but was not influenced by either response word characteristics in VDN naming.

Table 8 presents correlations between word characteristics and consensus and RT separately for each grammatical class in each VF condition. Image agreement was also included for the object naming task. Consensus highly correlated with RT in all the conditions. Length influenced only object naming in both VFs as well as frequency did. Imageability had its impact in all picture naming (PN) tasks in RVF condition while in LVF condition it correlated negatively with RT only in object naming task. Concreteness correlated with RT in RVF condition negatively in object and VDN naming tasks, and in LVF condition -- in action naming task. Image agreement did not influence RT in either VF of object naming task.

Overall, correlation analysis revealed that participants' consensus in naming was connected with some response word characteristics in object and action naming task, and was not influenced by any response word characteristics in VDN naming task. Consensus in naming had strong influence on RT in both VF conditions and in all picture naming tasks. It seems that consensus is a very powerful predictor of picture naming RT.

In spite of selected matched response items in both VFs and an absence of VF main effect in ANOVA results, correlation analysis revealed some differences in terms of impact of response word characteristics on RT in different VFs. Object naming RT in RVF was influenced by all response word characteristics while in the LVF concreteness effect disappeared. Action naming RT was influenced only by conceptual factors in

Table 9: Unique contributions to RT of each predictor when entered on the last step and partial correlations, separately for each PN task and VF

| | | Object | | Action | | VDN | |
|---|---|---|---|---|---|---|---|
| VF | Predictor | % Var | r= | % Var | r= | % Var | r= |
| R | Length | n.s. | n.s. | 12.1 | 0.40** | n.s. | n.s. |
| | Freq | 2.4 | -0.24** | n.s. | n.s. | n.s. | n.s. |
| | Image | n.s. | n.s. | 5.9 | -0.28* | n.s. | n.s. |
| | Concr | n.s. | n.s. | n.s. | n.s. | 5.7 | -0.27* |
| | Consensus | 40.0 | -0.70*** | 17.5 | -0.46*** | 9.3 | -0.34** |
| | Im Agr | n.s. | n.s. | -- | -- | -- | -- |
| L | Length | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| | Freq | 3.3 | -0.27** | n.s. | n.s. | n.s. | n.s. |
| | Image | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| | Concr | n.s. | n.s. | 3.4 | -0.25~ | n.s. | n.s. |
| | Consensus | 39.1 | -0.69*** | 32.3 | -0.62*** | 14.9 | -40** |
| | Im Agr | 1.3 | -0.17~ | -- | -- | -- | -- |

*** -- $p<0.001$; ** -- $p<0.01$; * -- $p<0.05$; ~ -- $p<0.07$; n.s. -- non-significant

both VFs. VDN naming processing was influenced only by concreteness in RVF condition and none of the response word characteristics impacted RT in the LVF.

In order to obtain more information of picture naming processing in VFs and to confirm results of correlation analysis, a stepwise multiple regression was conducted. Next section presents the results of the analysis.

### 6.2.4. Regression Analysis with Predictors/Word and Picture Characteristics as Variables

As in word naming experiments analysis, a stepwise multiple regression was performed with each predictor (word and picture characteristics) entered in the equation last to determine its unique contribution to RTs when all other predictors were controlled on the first step. Table 9 presents the results of a stepwise regression on RT for each picture naming task and VF separately. The results showed strong consensus contribution to the RT of object naming in both VFs and frequency contribution again in both VFs. These results are in agreement with correlation analysis (Table 8). However, a minor contribution of image agreement was revealed in LVF, a result that was not present in correlation analysis between word characteristics and RT (Table 8). It might be speculated that contribution of image agreement indirectly reflects activation of sensory features when an object picture was presented to the LVF (RH). Note also, that significant correlations of RT and other word characteristics (length, imageability, and concreteness) were not manifested in the regression analysis. Concerning action naming, the analysis showed that consensus made a significant contribution to the RT in both VFs. However, the behavior of other predictors was different in VFs: while concreteness slightly influenced RT in LVF, imageability and length in letters had their impact on RT in RVF. Note, that length contribution (12.1%) was quite strong and close to the consensus contribution (17.5%). These results again are in agreement with correlation analysis (Table 8) except the length contribution. Thus, the stepwise multiple regression revealed a quite strong hidden length factor in the action naming task. Regarding VDN picture naming, the analysis again showed significant contribution of consensus to RTs in both VFs, and concreteness contribution to RT in RVF. Although imageability and concreteness of VDN were highly correlated (Table 6), and correlation analysis with RT (Table 8) showed both imageability and concreteness correlation with RT in RVF, the regression analysis revealed (possibly) the most important influencing factor out of the two.

Thus, multiple regression analysis confirmed consensus contribution to the RT variance in both VFs. In addition, it revealed some differences in VF processing of different picture naming tasks. Object naming processing was influenced by frequency of the response words in both VFs. Action naming was influenced by lexical and conceptual factors when pictures were presented to the RVF and only by conceptual factor when pictures were presented to the LVF. VDN naming processing was influenced by conceptual factor in RVF and none of the word characteristics in the LVF. It seems that different information sources were activated to process different types of stimuli in different tasks.

### 6.3. Conclusion

The results indicated that perceptual and conceptual characteristics of the pictures were of great importance. ANOVA analysis suggested that action and especially VDN naming tasks required more complex (multiple-level) cognitive process than object naming independently on the field of presentation. In agreement with the expectations, no VF differences were obtained in ANOVA. Multiple regression analysis added some new information concerning processing of different types of pictures within and between VFs. While object naming processing was influenced by frequency in both VFs, the pattern of information activation in action and VDN naming tasks was quite different from that of object naming. Action naming tasks prompted an activation of lexical and conceptual information when the action picture were presented to the RVF (LH) and only conceptual information was activated in the LVF condition. VDN behaved in a sense similarly to action naming processing when presented to the LH (RVF). LVF presentation mode, however, did not prompted activation of any of the word characteristics. Finally, in agreement with other studies (Kremlin at al., 2000; Meschyan & Hernandez, 2002), consensus for all picture naming types and frequency for object naming appeared to be a very strong predictor of RT.

Thus, while word naming task appeared to clearly differentiate between word characteristics and showed differential brain strategies, picture naming task showed both differentiation and similarity within- and between VF processing. LVF (RH) presentation considerably increased consensus contribution to the RT of action and VDN naming in comparison to its contribution to the RVF (LH) RT. Quite strong consensus contribution of object naming did not change. As it was noticed before, consensus in a way reflects number of alternative names. Thus, the higher is the consensus, the smaller is the number of alternative names, hence, competition between alternative names is weak, and the opposite: the lower is the consensus, the higher is the number of alternative names and the stronger is the competition between them. It could be argued that in the cases of action and VDN naming, picture presentation to the LVF (RH) activated more related lexical items than the presentation to the RVF (LH). There is some evidence to suggest that RH activates multiple number of meanings while LH inhibits unrelated to the target/context meanings (e.g., Chiarello, 1991; Beeman et al, 1994; Faust & Chiarello, 1998; Coney & Evans, 2000). So, possibly, bunch of factors such as complex processing of visual and conceptual information and low consensus prompted RH to activate multiple possible associated with a picture lexical items when action picture was presented to the LVF (RH). Note that LVF (RH) presentation slightly activated concreteness of produced verbs and none of the VDN response word characteristics. Thus, the main "load" in processing was, probably, the activation of multiple related to the pictures meanings/lexical items. RVF (LH) presentation of action pictures activated lexical information (length) of verbs (logogen system) and imageability (imagen system). VDN naming was also influenced by conceptual factor in RVF but length played no role in the processing. This result showed once again that VDN naming differed from both, object and action naming processes. Recall that picture stimuli for action and VDN naming were the same. Moreover, 80% of response words overlapped in their roots. The superficial difference was just a bound morpheme that carried different types of information for these grammatical classes. It seems that both, ANOVA and multiple regression analysis showed that VDN naming was more complex than the naming of other two types of picture naming and that other factors that have not been explicitly taken into account, governed VDN processing.

The results suggest that in the case of considerably easy object naming task and considerably high object naming consensus, presentation to both VFs initially did activate similar mechanisms and/or information sources of the two hemispheres. In terms of DCT, it activated both imagen (consensus is related to object recognition/concept activation also) and logogen systems (frequency of the response word and indirectly number of alternative names) in both hemispheres. From other side, subjective frequency rating is / may be related to familiarity of the object (Johnson et al., 1994), and consensus correlated with the length of the response words as well as with imageability and concreteness. Thus, it seems that to separate completely and confidently response word characteristics along one line/direction/dimension appears to be impossible. The characteristics are interrelated as well as the DCT systems are. Based on just RT integrative measure it is hard to determine how and when the systems interact with each other.

To conclude, the experiment demonstrated that picture and response word attributes are of importance in processing and that VF differences may be revealed by examination of contribution of each factor into the RT variance. On the other hand, the results demonstrated that the taken into account characteristics are not enough to understand the interplay and contribution of each of them into the process. An implication is that future study is required with better account of word and picture characteristics. That is, larger number of factors has to be taken into account (age of acquisition, object familiarity, picture complexity, number of alternative responses, etc.).

# CHAPTER 7. EEG EXPERIMENTS

## 7.1. EEG and Gamma-Band Frequency

Brain electrical activity is recorded by the use of EEG technique. Several brain rhymes were identified as constituents of EEG record. Maybe, the most famous one is the alpha rhythm. Alpha activity occurs approximately from 8 to 12 times per sec (Hz). It is mostly associated with mental activity (or the resting state) -- the amplitude of alpha rhythm usually decreases with the increase of mental activity. Other brain rhymes also were identified. Theta-band activity (4-8 Hz), beta (12/14 - 25/30 Hz), delta activity (1-4 Hz) are associated with mental processes, attention, recognition, perception, working memory processes and cognition in general (e.g., Sarnthein et al., 1998; Kopell et al., 2000; Haenschel et al., 2000; Tesche & Karthu, 2000). Gamma-band activity (25/30 - 60/70 Hz) was shown to be related to sensory-motor processes, auditory system, attention and object recognition, language processing (e.g., Sauvé, 1999; Pantev et al., 1991; Haenschel et al., 2000; Pulvermüller et al., 1995; Pulvermüller & Mohr, 1996). Gamma activity is associated with the so-called feature binding (possibly, binding is an integration of distributed information into a unified representation). The idea is that gamma may be time and phase locked* to the stimulus which probably reflects synchronously active neural cell assemblies and/or a neural activity generator. This synchrony may be observed both in closely related areas and in widely distributed, and different time-phase-space and frequency locked patterns may be noticed in different conditions, tasks, stimuli types, etc. Research done by Pulvermüller et al. (1995) and Pulvermüller & Mohr (1996) shows that gamma activity is closely related to language/linguistics processing and may reflect (among other possibilities) the concept of associative learning mechanism (Hebbian cell assemblies). Miltner et al. (1999) experimentally showed that gamma activity is involved in associative learning mechanism.

Gamma oscillations may also occur with variable latency, reflecting a stimulus-induced activity. I am more interested in how gamma activity is (might be) related to cognition and language processing in particular, rather than the physiological mechanisms by which gamma might be generated. Thus, I will try to

* Other frequency bands may also be time and phase locked to the stimulus and also be synchronized between different frequency bands.

focus on gamma activity, induced by a stimulus and on how the activation is related to different experimental conditions and word characteristics.

## 7.2. Method

### 7.2.1. Subjects

6 subjects (3 males and 3 females) participated in the experiments. All were university students with an average age of 25.3 years (ranged from 20 to 33). They were all right-handed, Bulgarian monolinguals. All of them had normal or corrected to normal vision. Participants were paid 20$ for the participation. None of them has participated in the RT experiments. 3 of them (1 male and 2 females) were assigned to verb-noun condition in the two, word and picture naming tasks, and another 3 (2 males and 1 female) were assigned to verb-derived noun-noun condition in the two naming tasks. The data of 3 of them had to be discarded because of technical reasons (absence of signal in the EEG record/amplifier blocking). For the analysis data of two subjects were selected with the least eye movement contamination. Both subjects were males, 20 and 29 years old.

### 7.2.2. Stimuli and Design

Word and picture stimuli and the manner of presentation were the same as in RT experiments.

Two types of the design were used in the analyses. For word naming task, the independent variables were Visual field (Left and Right VF), Word Frequency (Low, Medium, and High), Imageability (Low, High), Grammatical Class (Noun and Verb or Noun and Verb-Derived Noun) and Hemisphere (LH and RH) or Channel pair (10 channels, see below) with area of gamma waves as dependent measure. For picture naming task the independent variables were Visual field (Left and Right VF), Imageability (Low, High), Grammatical Class (Noun and Verb or Noun and Verb-Derived Noun) and Hemisphere (LH and RH) or Channel pair (10 channels, see below) with area of gamma waves as dependent measure (for ANOVA). Frequency of the produced words in picture naming task was controlled.

Since RT experiments showed that multiple regression analysis was more reliable and informative than correlation, in the experiments with gamma area as a dependent measure only multiple regression analysis was done. Predictors of gamma oscillations in regression analysis were length in letters, frequency, imageability and concreteness of the words in the two, word naming and picture naming tasks. Trials on which words in word naming experiments were named differently from the target were considered as naming errors and were not subjected to the analysis. Trials on which pictures were named with a word that was not present in our database of word characteristics or with a word that had no visual or conceptual relation to a picture, were not analysed either.

### 7.2.3. Procedure

The procedure was the same as in RT experiments except mask presentation and the intertrial interval that was chosen to be a random number between 5 and 7 sec in word naming task and between 8 and 10 sec in picture naming task.

Experiment consisted of two experimental parts with a 3-week or more, interval. Each experimental part consisted of word naming (noun and verb, or noun and verb-derived noun) and of picture naming (object, action, or verb-derived noun naming). Assignments of the tasks were randomized. The appearance of stimuli in either VF in word naming was balanced across experimental parts. So, in each experimental part subjects were run on word naming (two word classes) and on one of the picture naming tasks. As a result, each subject was run twice on word naming task on different counterbalanced by VF orders, and on two picture naming tasks.

Subjects were asked to try not to blink or move their eyes in the interval from the appearance of fixation cross to their response.

### 7.2.4. Recordings

The EEG was recorded by means of Ag/AgCl electrodes placed symmetrically over the left and right hemispheres. The set of electrodes covered Broca's and its homologous area, sensory-motor area (covering the supplementary motor area -- SMA), Wernicke's and its homologous area, parietal and occipital areas. A schematic representation of electrode location is presented in Appendix 3. The electrodes were denoted respectively as F7, F8, C3', C4', T5, T6, P3, P4, O1, and O2 (10/20 system, C3' and C4' positioned 1 cm anterior with respect to the standard C3 and C4 location). The linked earlobes served as reference. EOG was recorder bipolarly from the left and right cantus to detect both vertical and horizontal eye movements. The EEG and EOG signals were amplified using Nihon Kohden EEG - 4314F/Japan (-3 dB cut-off frequencies of 0.03 - 120 Hz) and recorded together with markers of the stimuli by an analog tape recorder (TEAC XR 510C, Japan; DC-2.5 kHz). The marker of a stimulus was a 100-ms TTL signal coming from the Button-Box on a separate channel simultaneously with the stimulus appearance. The signals were digitized off-line (10 bit A/D converter, 256 samples/sec; Kaminsky & Krekule, 1994).

### 7.2.5. Data analysis

All the computations/data processing of EEG were performed on IBM PCs using MATLAB package and homemade program system and (mainly) AcqKnowledge 3.2.4 for Microsoft Windows package system. The data records were filtered using Blackman band pass filter with number of coefficients 100 from 35 to 45 Hz (medium gamma frequency). Integral function of absolute value of the obtained gamma waves (i.e., gamma area, measured in msec x μV) was taken separately for each channel and each accepted stimulus data after stimulus offset for 1.2 sec of word naming task experiments and for 1.4 sec of picture naming task experiments. An example of gamma waves for a single trial may bee seen in Appendix 4.

The data of two subjects were analyzed separately. First, I will consider word naming experiments and then picture naming.

For the analysis with hemispheres (LH, RH) as one of the independent variables, the data were averaged by items and hemispheres over channels. Regression analysis for each separate hemisphere was done on the averaged by hemispheres set of data.

## 7.3. Results and Discussion

### *7.3.1. Word Naming*

#### 7.3.1.1. Data Reduction

##### 7.3.1.1.1. Noun and Verb Naming Experiments

Trials on which no response was registered (1.25%) and trials with erroneous response (3.75%) were excluded from the analyses. In addition, trials or data of separate channels with bad quality of a signal (1.7% and 1.1%, respectively) were also removed. Thus, a total of 92.2% of the originally collected EEG data was included in further analyses.

##### 7.3.1.1.2. Noun and VDN Naming Experiments

Trials on which no response was registered (0.4%) and trials with erroneous response (15%) were removed from the data set. Trials or data of separate channels with bad quality of a signal (0.4% and 1.1%, respectively) were also removed. Thus, a total of 83.1% of the originally collected EEG data was included in data analyses.

### 7.3.1.2. Noun and Verb naming

#### 7.3.1.2.1. Analysis with Hemispheres as one of the independent variables

A 2 (VF) x 2 (Hemispheres) x 2 (Grammatical Class) x (Imageability) x 3 (Frequency) analysis on gamma wave area revealed three significant main effects. A main effect of Imageability ($F_{(1,402)}=5.82$; $p<.05$) showed that high imageable words elicited lower gamma area (0.70) than low imageable (0.74). A significant main effect of Hemispheres ($F_{(1,402)}=18.42$; $p=.00$) revealed that gamma area in LH was larger (0.75) than in the right one (0.69). A main effect of Grammatical class ($F_{(1,402)}=41.15$; $p=.00$) showed that verb processing elicited smaller gamma area (0.67) than noun processing (0.77). No main effect of VF was found.

Thus, the results appeared to be consistent with the RT word naming experiment in terms of differential processing of the two grammatical classes and sensitivity to the imageability levels of the words. It seems that gamma showed to be a measure of processing difficulty, analogous to the RT.

A significant interaction between VF and Frequency ($F_{(2,402)}=3.16$; $p<.05$) is shown in Figure 1. Significant differences were found between gamma area elicited by low frequency words presented in the RVF and all the other means except data point of medium frequency words presented in the LVF. So, words, presented to the LVF elicited the same gamma independently of frequency of these words while gamma waves were affected by frequency of the words presented in the RVF. It seems that in this case gamma waves represent a kind of activation and not processing difficulty since low frequency words elicited lower gamma waves than higher frequency words in RVF. Thus, it could be suggested that gamma has a property to show different strategies/patterns of processing: both activation and processing difficulty which, probably, depend on different word properties and on experimental conditions.

A significant interaction between Imageability and Frequency ($F_{(2,402)}=6.07$; $p<.01$) is shown in Figure 2. The interaction showed that frequency played an activation role only in the low imageable words condition. Post hoc comparison revealed significant differences between mean gamma area elicited by low imageable and high and medium frequent words and no significance between medium and high frequency words in low imageability condition. Words in high imageability condition elicited non-significant among

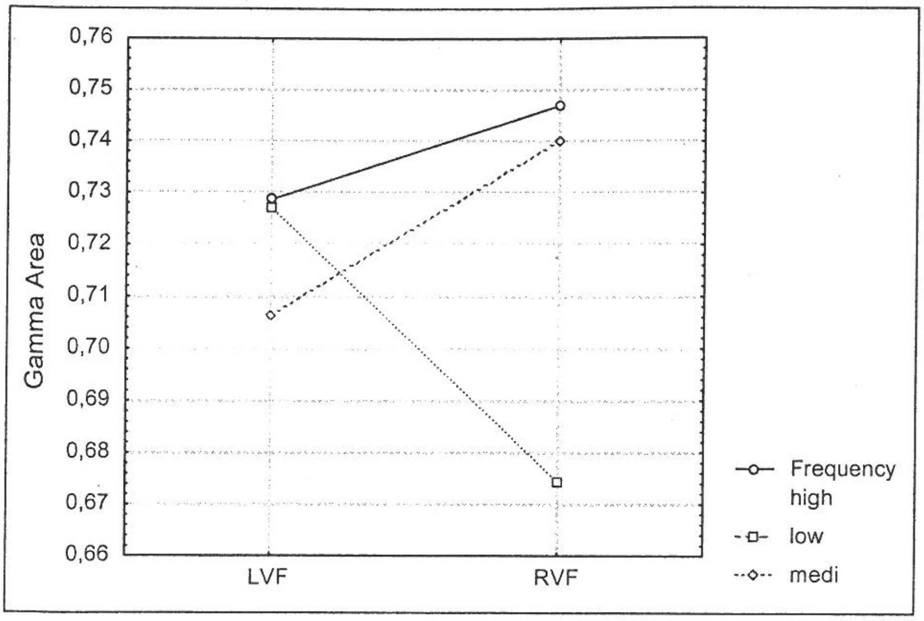


Figure 1. VF by Frequency interaction, WN

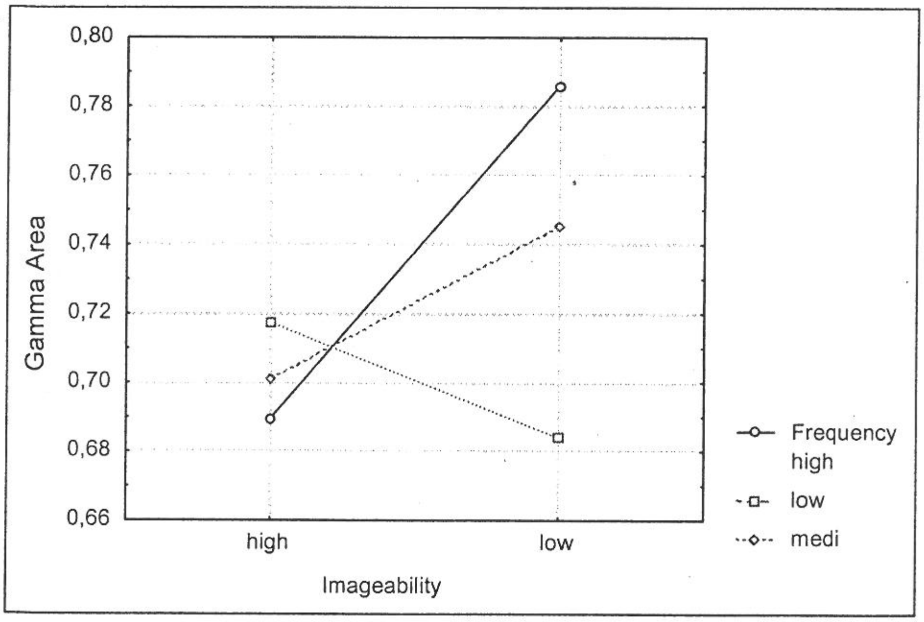


Figure 2. Imageability by Frequency interaction, WN

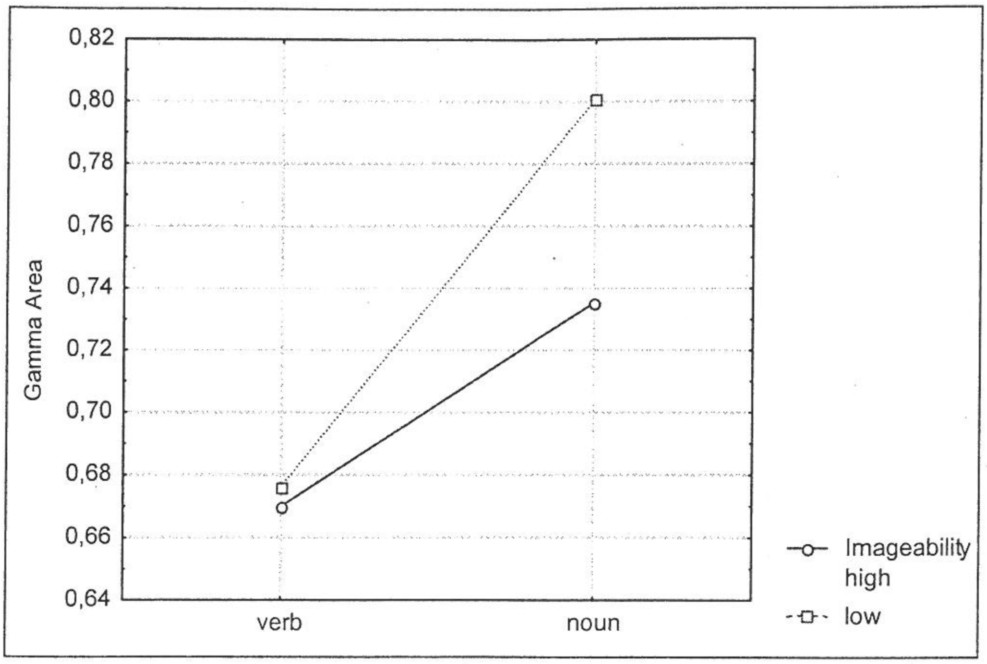


Figure 3. Grammatical class by Imageability interaction, WN

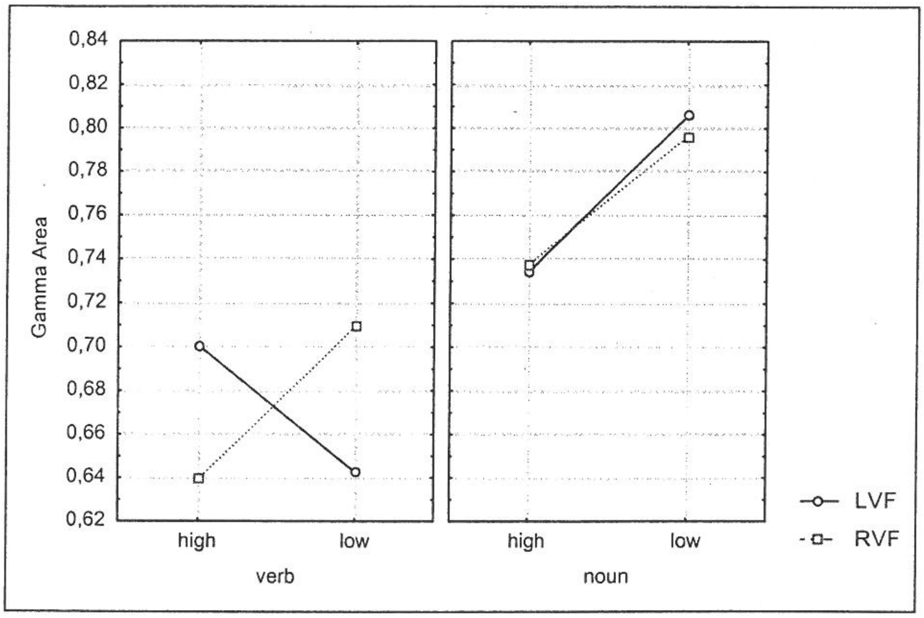


Figure 4. Grammatical class by Imageability by VF interaction, WN

each other mean gamma areas in high imageability condition. The difference between imageability levels was found between low frequent high imageable words and high frequent low imageable words.

It seems that high imageability level cancelled frequency effect which was manifested in low imageability condition showing gamma activation pattern.

A significant interaction ($F_{(1,402)}$=3.99; p<.05) between Grammatical class and Imageability is shown in Figure 3. Verbs were processed with significantly lower gamma area than nouns independently on imageability levels. Imageability played a role only in the case of nouns: low imageable nouns produced higher gamma activation than high imageable nouns. Note, that in this case gamma showed processing difficulty pattern and not activation. Significant differences were found between all the means except gamma area means in the case of verb processing.

A significant three-way interaction between Grammatical class, Imageability and VF ($F_{(1,402)}$=5.63; p<.05) is shown in Figure 4. The interaction gives an additional information about the processing peculiarities: it appears that in noun condition not VF but only imageability played a role and influenced area of gamma oscillations, i.e., low imageable nouns elicited higher gamma waves than high imageable nouns independently on VF. While in verb condition the picture was quite different: VF along with imageability influenced gamma oscillations but in a different way. When verbs were presented to the LVF, gamma showed activation, i.e., high imageable verbs elicited significantly higher gamma than low imageable verbs. However, when verbs were presented to the RVF, gamma showed processing difficulty pattern, i.e., high imageable verbs were processed with significantly lower gamma than low imageable verbs.

No other significant main effects or interactions were found.

Thus, the results showed some consistency with the RT data, i.e., verbs were processed with smaller gamma elicited than nouns. In addition, the results revealed different strategies in the processing in terms of produced gamma oscillations: while noun processing showed processing difficulty pattern independently on VF (high imageable nouns elicited smaller gamma areas than low imageable noun), verb processing indicated that the strategy might depend on VF. Verb presentation to the RVF showed processing difficulty strategy but presentation to the LVF produced activation strategy pattern (high imageable verbs elicited higher gamma oscillations than low imageable verbs). Thus, in addition to differential processing between the two grammatical classes, the analysis showed different processing strategies within each grammatical class that depended on imageability levels in the case of nouns and on the field of presentation in the case of verbs.

### 7.3.1.2.2. Analysis of gamma oscillation in all 10 channels

In order to trace gamma oscillation behavior in more details, a 2 (Imageability) x 2 (VF) x 2 (Grammatical class) x 3 (Frequency) x 10 (Channels) analysis was conducted. In this analysis I was interested only in channels picture as a whole. Thus, only main effect of Channel and interactions with Channel as an independent variable will be presented. After that, I will present the results with every symmetrical pair of channels as one of independent variable separately.

Analysis with 10 channels revealed significant main effect of Channels ($F_{(9,1963)}$=228.74; p=0.00) and significant interaction ($F_{(9,1963)}$=2.52; p<.01) between Channels and Grammatical class (Figure 5). It is seen that the main gamma activation was in O1 and O2, P4, T5 and F7. Surprisingly, there was no activation in SMA areas (C3 and C4) in the case of verb processing. Several possible explanations of inconsistency with the results of Pulvermüller et al. (1996; 1999) may be provided. One is that the verb stimuli of present experiments were not controlled for motor associations. Another reason may lie in the used gamma-band range. Pulvermüller et al. (1996; 1999) found gamma activation in lower gamma range (25-35 Hz) than it was used as a measure of processes in the present experiments (35-45 Hz). In addition, Pulvermüller et al. (1996; 1999) used not word naming but lexical decision task with central presentation mode. The lateralized presentation may put an additional demand on occipital areas. Probably, this may be one of the reasons that occipital areas elicited high gamma in response to both grammatical classes. Recall that gamma area was measured from the *offset* of the stimuli. So, possibly, high gamma activation in O1 and O2 reflects an activation of short-term visual memory, in addition to other possible underlying reasons such as visual word processing on different levels.

### 7.3.1.2.3. Analysis of gamma oscillation in pairs of channels

Aiming to reveal how every variable influence gamma waves in each pair of channels and which areas were responsible for the effects and interactions found in the previous analysis, a separate analysis was done for every channel pair as an independent variable.

*F7, F8* 2 (Imageability) x 2 (VF) x 2 (Grammatical class) x 3 (Frequency) x 2 (Channels) analysis revealed the only significant main effect of channels ($F_{(1,386)}$=193.91; p=0.00). It showed that gamma area was larger in F7 (0.71) than in F8 (0.50).

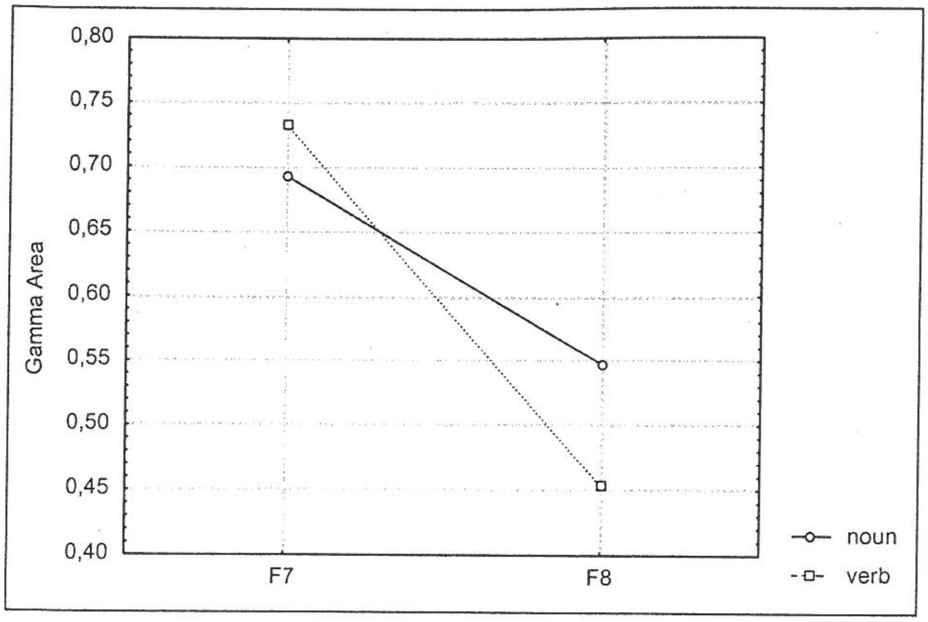


Figure 7. Grammatical class by Channel interaction, WN

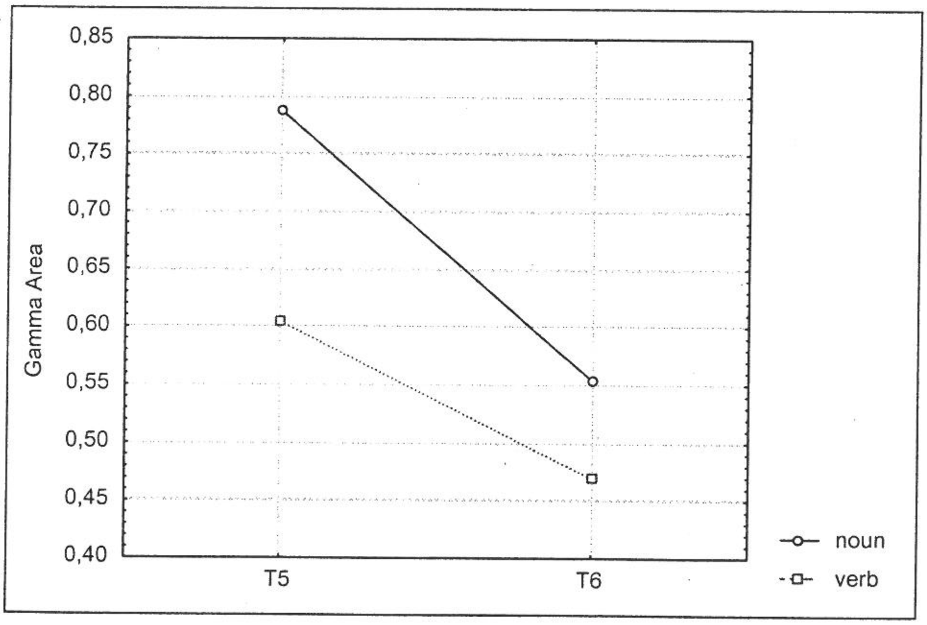


Figure 8. Grammatical class by Channel interaction, WN

A significant interaction between Frequency and Imageability ($F_{(2,386)}$=4.46; p<.05) is shown in Figure 6. It showed similar pattern (see Figure 2) such that gamma area was not sensitive to the frequency levels in high imageability condition and was sensitive in low imageability condition. Significant differences were obtained between mean gamma areas elicited by high frequency and low imageability words and all the other mean areas. Thus, in F7 and F8 gamma showed activation in low imageability condition, i.e., high frequency words elicited larger gamma area than medium and low frequency words independently on VF. Thus, it seems that F7 and F8 channels were responsible for the obtained Frequency x Imageability interaction on the averaged data set (Figure 2).

A significant interaction between Grammatical class and channel ($F_{(1,386)}$=19.32; p=.00) is shown in Figure 7. Significant differences were found across all the mean gamma areas. Thus, verbs elicited larger gamma area in F7 (Broca area) than nouns, and nouns elicited larger gamma area in its homologous area than verbs. No other significant main effects or interactions were found.

Overall, frontal areas were sensitive to frequency levels in low imageability condition and showed different activation patterns between elicited by nouns and verbs gamma areas.

*C3, C4* Analysis revealed a significant main effect of Frequency ($F_{(2,401)}$=4.91; p<.01). It showed that high frequency words elicited significantly larger gamma area (0.54) than medium (0.50) and low (0.50) frequency words. A significant main effect of Channel ($F_{(1,401)}$=1927; p=.00) showed that gamma was more active in C3 (0.54) than in C4 (0.49). Possibly, higher activation in C3 area could be attributed to an activation of articulatory system.

A significant main effect of Grammatical class ($F_{(1,401)}$=4338; p=.00) showed that nouns elicited larger gamma (0.55) than verbs (0.48). Thus, SMA showed processing difficulty pattern but not gamma activation associated with motor associations.

The same significant interaction between Frequency and Imageability (see Figure 6) was obtained ($F_{(2,401)}$=11.36; p=.00). No other significant interactions were revealed.

Overall, gamma elicited in SMA, similar to frontal areas, seems to be sensitive to frequency levels of the words and to grammatical differences between the words.

*T5, T6* Two significant main effects were obtained. A main effect of Channel ($F_{(1,402)}$=87.46; p=.00) showed that gamma oscillations were more active in the T5 area (0.70) than in T6 (0.51). A main effect of Grammatical class ($F_{(1,402)}$=46.43; p=.00) revealed that noun processing elicited larger gamma (0.67) than verb processing (0.54).

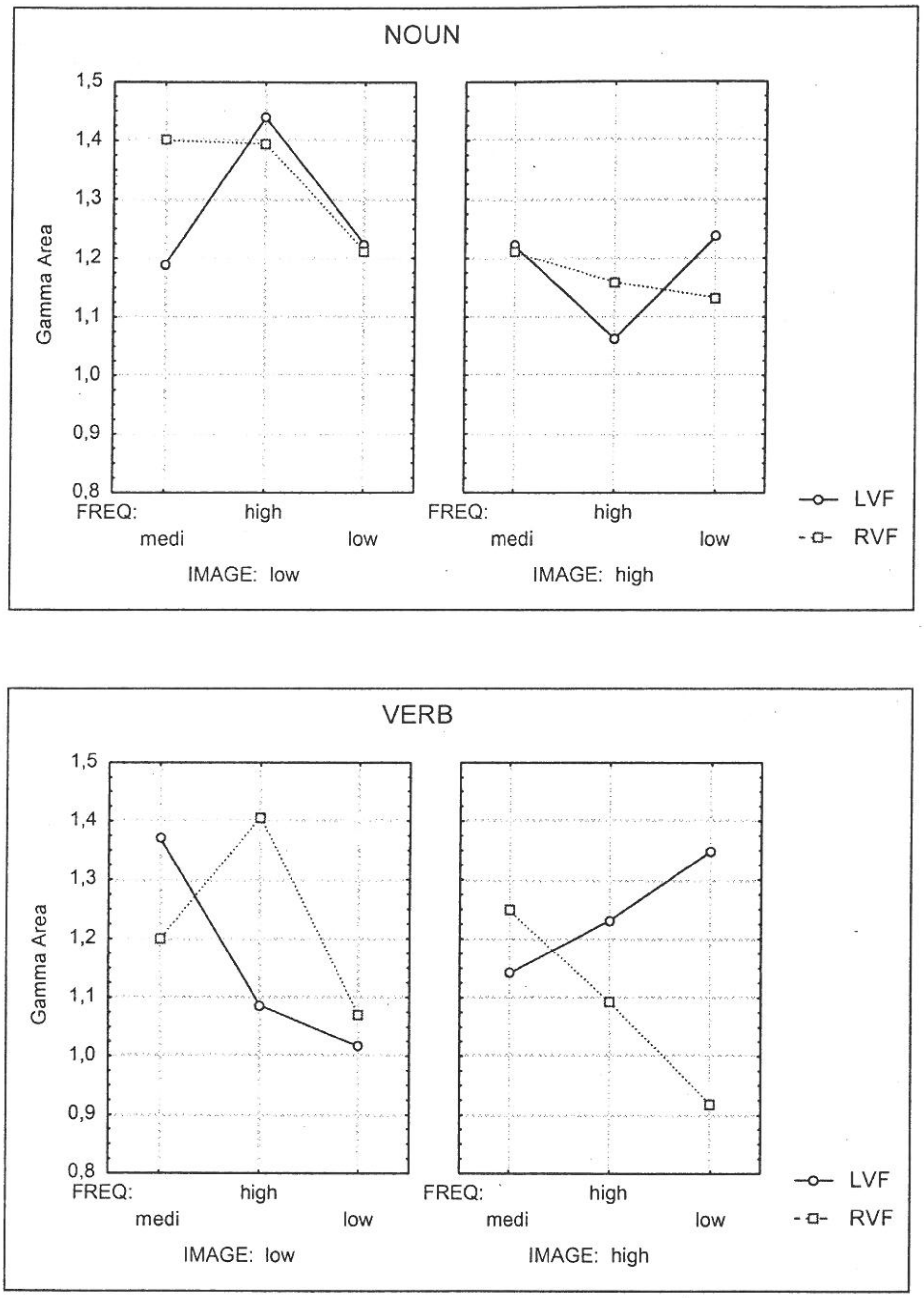


Figure 9. Grammatical class by VF by Imageability by Frequency interaction, WN

A significant interaction between Channel and Grammatical class ($F_{(1,402)}$=6.30; p<.05) is shown in Figure 8. Significant differences were found across all the area means except mean gamma in T6 when noun was to be named and in T5 when verb was to be named (p< .052). Thus, the interaction just confirmed the two main effects. No other significant main effects or interactions were found. Note, that here the sensitivity to the frequency levels disappeared and remained only the sensitivity to the grammatical class differences.

*P3, P4* Here again, two main effects were found to be significant. A main effect of Channel ($F_{(1,401)}$=57.49; p=0.00) showed that the task elicited stronger activation in P4 (0.81) than in P3 (0.61). A main effect of Grammatical class ($F_{(1,401)}$=8.38; p<.01) showed that noun naming elicited more active gamma (0.75) than verb naming (0.67).

A significant three-way interaction between VF, Imageability and Grammatical class ($F_{(1,401)}$=4.72; p<.05) was obtained, that is, the same interaction that is shown in Figure 4. Thus, P3 and P4 were responsible for the interaction obtained on the averaged data file that showed different processing strategies that were depended on grammatical class and presentation field. Note, that parietal channels were the first that elicited more active gamma waves in the RH (P4) than in the left one (P3).

*O1, O2* The only obtained significant main effect of Channel ($F_{(1,373)}$=17.18; p=.00) showed that gamma area was larger in O1 (1.30) than in O2 (1.12). No other significant main effects were obtained.

A four-way interaction between Grammatical class, VF, Imageability and Frequency ($F_{(2,373)}$=4.10; p<.05) is shown in Figure 9. In noun condition neither VF nor frequency or imageability of the stimuli had an effect on gamma activation (no significant differences were found across all the means). That is, in occipital areas all nouns elicited the same gamma oscillations unaffected by either experimental condition. In high imageable verb condition it appeared that VF affected gamma oscillation only in low frequency condition: when low frequency verbs were presented to the RVF, gamma area was lower (0.92) than when these low frequency verbs were presented to the LVF (1.35). In low imageable verb condition significant differences were found between mean gamma areas of low frequency verbs presented to the LVF (1.02) and high frequency verbs, presented to the RVF (1.41). Interesting to notice that in low imageable condition high frequency verbs produced the opposite (although insignificant; p<0.09) to the high imageable low frequency verb condition trend. That is, presentation to the RVF of low imageable and high frequency verbs produced more gamma activation than presentation to the LVF of low imageable and high frequency verbs, whereas presentation to the RVF of high imageable and low frequent verbs elicited less gamma activation than presentation to the LVF high imageable and low frequent verbs.

Overall, it could be said that frontal and supplementary motor areas were responsible for the activation frequency pattern of low imageable words, whereas grammatical class effect (verbs elicited lower gamma than nouns) was observed partially in frontal and mainly in SMA, temporal and parietal areas. Another noticeable result was that all channels but parietal, showed more LH activation than the right one. Thus, only in parietal areas RH activation was larger than LH activation. Gamma in occipital areas was not sensitive to either imageability or frequency levels of nouns, while verb characteristics produced differential processing patterns. Thus, ANOVA results confirmed that in the used experimental paradigm verbs were processed easier than nouns. In addition, the results showed that the processing of verbs was linked with more complicated interplay of word characteristics, especially in more posterior areas. Finally, the analysis revealed two different types of gamma behavior (activation and processing difficulty), probably connected to different types of word characteristics. VF presentation mode significantly affected gamma elicited by verbs in parietal and occipital areas while noun presentation left gamma unaffected by VF.

Next section presents ANOVA results of word naming with noun and verb-derived noun types of stimuli.

#### 7.3.1.3. Noun and Verb-Derived Noun Naming

##### 7.3.1.3.1. Analysis with hemispheres as one of the independent variables

A 2 (VF) x 2 (Hemispheres) x 2 (Grammatical Class) x (Imageability) x 3 (Frequency) analysis on gamma wave area revealed two significant main effects and no significant interactions. A main effect of VF ($F_{(1,354)}$=8.23; p<.01) showed that words, presented to the LVF, produced less gamma activation (0.65) than words, presented to the RVF (0.70). A main effect of Hemispheres ($F_{(1,354)}$=10.81; p<.01) revealed that presented words elicited less gamma activation in the LH (0.64) than in the right one (0.71). Thus, the analysis showed that the two types of words with their imageability and frequency characteristics were processed equally in terms of gamma activation. In addition, the analysis showed difference between the subjects; recall, that the previous analysis with noun-verb naming showed no VF main effect and the opposite trend of hemispheric activation. Probably, this difference may also be attributed to another experimental paradigm: here stimuli were nouns and VDNs.

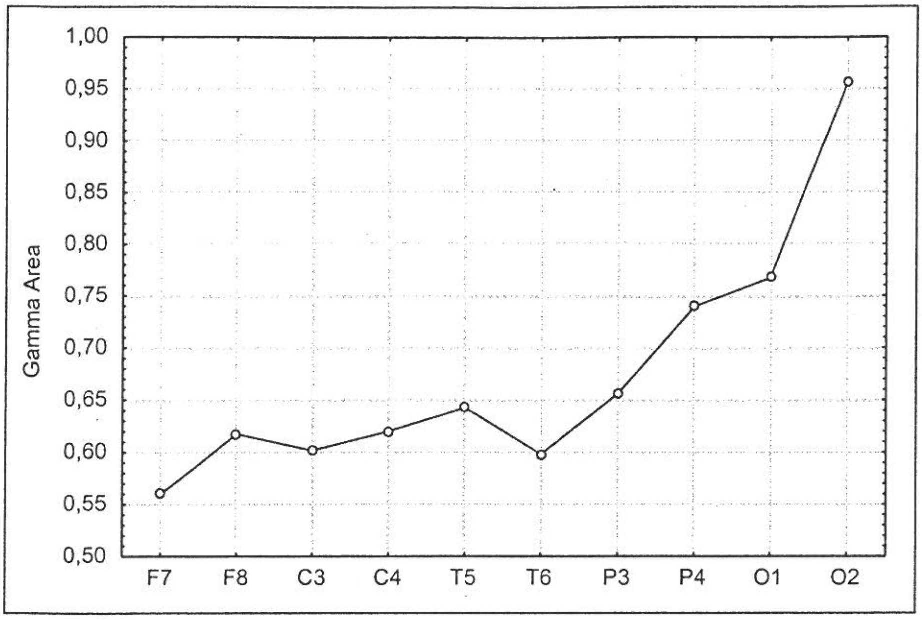


Figure 10. A main effect of Channel, WN

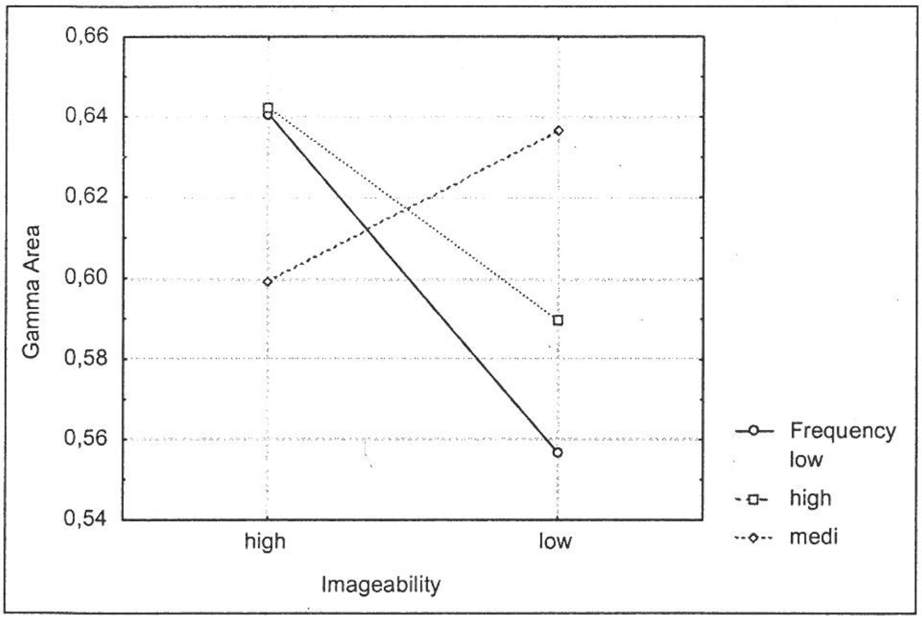


Figure 11. Imageability by Frequency interaction, WN

#### 7.3.1.3.2. Analysis of gamma oscillations in all 10 channels

The same analysis with 2 (Imageability) x 2 (VF) x 2 (Grammatical class) x 3 (Frequency) x 10 (Channels) design was conducted to look at the gamma behavior in all channels together. The analysis with 10 channels revealed significant main effect of Channels ($F_{(9,1743)}$=48.98; p=0.00). In Figure 10 it is seen that the main gamma activation was in O1, O2 and P4. Thus, P4 (RH) produced larger than P3 (LH) gamma as in previous subject. However, the occipital pattern was different: here O2 was richer in gamma activation than O1. In addition, no interaction with grammatical class was found.

#### 7.3.1.3.3. Analysis of gamma oscillations in pairs of channels

Here again, a separate analysis was done for each pair of channels as an independent variable in order to explore the influence of variables on gamma activation in more details.

*F7, F8* 2 (Imageability) x 2 (VF) x 2 (Grammatical class) x 3 (Frequency) x 2 (Channels) analysis revealed the only significant main effect of channels ($F_{(1,349)}$=7.92; p<.01). It showed that gamma area was larger in F8 (0.62) than in F7 (0.56).

*C3, C4* One main effect of VF was found ($F_{(1,354)}$=6.07; p<.05). Words, presented to the RVF, elicited more active gamma (0.64) than when presented to the LVF (0.59). A significant interaction between Imageability and Frequency ($F_{(2,354)}$=3.58; p<.05) also was obtained (Figure 11). High imageable words produced insignificant mean gamma areas across frequency levels, while low imageable words elicited significantly larger gamma area for medium frequency words (0.64) than for low frequency words (0.56). Post hoc analysis revealed also significant differences between elicited gamma of low imageable and low frequency words and high imageable high and low frequency words. That is, for low frequency words imageability was important in terms of produced gamma waves: gamma was more active in high imageable word condition than in low imageable. It appeared that in SMA of the two subjects gamma oscillations were sensitive to the frequency levels of low imageable words.

*T5, T6* Two significant main effects were obtained. A main effect of VF ($F_{(1,353)}$=6.44; p<.05) showed that words, presented to the RVF, produced larger gamma area (0.64) than words, presented to the LVF (0.60). A main effect of Channel ($F_{(1,353)}$=5.49; p<.05) showed more gamma activation in T5 (0.64) than in T6 (0.60). No significant interactions were found.

*P3, P4* Here again, the same two main effects were found. A main effect of VF ($F_{(1,354)}$=4.80; p<.05) showed that words, presented to the RVF, elicited larger gamma area (0.73) than words, presented to the LVF (0.67). A main effect of Channel ($F_{(1,354)}$=10.84; p<.01) revealed more gamma activation in P4 (0.74) than in P3 (0.66). There were no significant interactions.

*O1, O2* A significant main effect of VF ($F_{(1,333)}$=8.68; p<.01) found more gamma activation when words were presented to the RVF (0.91) than to the left one (0.81). A main effect of Channel ($F_{(1,333)}$=32.72; p=.00) showed larger gamma area in O2 (0.96) than in O1 (0.77).

Thus, all the channels but placed in frontal lobes, were responsible for the main effect of VF. In all these channels words, presented to the RVF, elicited larger gamma areas than words, presented to the LVF. SMA were responsible for the obtained Frequency x Imageability interaction. No hemispheric differences were obtained in SMA. However, hemispheric differences were observed in all the other channels that showed larger RH than LH activation. The only exception was in the temporal areas: there LH was more active than RH. No Grammatical class effect was revealed, that is, nouns and verb-derived nouns were processed in a similar mode.

### 7.3.1.4. Summary of the Results

ANOVA of two experiments revealed individual differences between the subjects in processing of two different grammatical pairs (verb/noun and VDN/noun). While the data of one subjects showed no main effect of VF, the data of the second subject showed gamma sensitivity to the field of presentation: stimuli presentation to the RVF (LH) produced more active gamma than stimuli presentation to the LVF (RH). At the same time, more RH activation was noticed in the second (VDN/noun) subject than in the first one (verb/noun). The overlapping activation trend was noticed only in parietal regions: P4 elicited larger gamma than P3. In addition, both subjects showed SMA sensitivity to the frequency levels of low imageable words. In addition, verb/noun experiment supported RT results in terms of easier verb processing while VDN/noun experiment did not show any differences in the processing of two grammatical classes. Recall that RT results showed that VDN naming took longer to name than noun.

Another noticeable results was that elicited gamma in verb/noun naming experiment showed different processing strategies (activation and processing difficulty), probably connected to different types of word characteristics. Data of the VDN/noun naming experiment showed only an activation pattern in SMA.

Next section will consider the results of regression analysis.

### 7.3.1.5. Regression analysis with predictors as variables

Stepwise multiple regression analyses was conducted to study the relationship between each word characteristics in each VF and hemisphere and each VF and channel and elicited gamma areas. In this analysis could be revealed not only hidden relationships but also revealed and/or confirmed patterns of different strategies that were found in ANOVA analyses that is, either activation or processing difficulty ones. Stepwise multiple regression analyses for each separate hemisphere was done on the averaged by hemispheres set of data.

#### *7.3.1.5.1. Noun and Verb Naming*

##### 7.3.1.5.1.1. Regression analysis for each hemisphere

A stepwise multiple regression analysis was performed with each predictor (word characteristic) entered in the equation last to determine its unique contribution to gamma area when all other predictors were controlled on the first step. The analysis revealed the only length contribution to the RH gamma area with the RVF verb presentation (% of explained variance = 8.1; partial correlation $r = 0.30$; $p < 0.05$) and strong noun imageability contribution to the LH elicited gamma with LVF type of presentation (% of explained variance = 9.3; partial correlation $r = -0.31$; $p < 0.05$).

The results showed that although gamma area was not as sensitive to the word characteristics as is was RT, it is still possible to apply regression analysis and obtain some results that may shed an additional light to the understanding of word processing. In an endeavor to trace further the influence of word characteristics on produced gamma areas in each condition, the same kind of analysis was done for each channel separately. In such a way it would be possible to reveal not only the area(s) that produced the obtained above results but also to obtain some other possible impact of word characteristics that was canceled in the overall hemispheric analysis.

Table 10: Unique contributions to gamma area of each predictor when entered on the last step and partial correlations, separately for each VF, each channel and grammatical class

(a)

| VF | Channel | Word | Length, %Vars (*r*=) | Frequency, %Vars (*r*=) | Imageability, %Vars (*r*=) | Concreteness, %Vars (*r*=) |
|---|---|---|---|---|---|---|
| R | F7 | Noun | n.s. | n.s. | n.s. | n.s. |
| | F8 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T5 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T6 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | O1 | Noun | n.s. | n.s. | n.s. | n.s. |
| | O2 | Noun | n.s. | n.s. | n.s. | n.s. |
| L | F7 | Noun | n.s. | n.s. | n.s. | n.s. |
| | F8 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C4 | Noun | n.s. | 1.02 (0.25~) | n.s. | n.s. |
| | T5 | Noun | n.s. | n.s. | 6.61 (-0.26~) | n.s. |
| | T6 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P3 | Noun | n.s. | 9.15 (0.31*) | n.s. | n.s. |
| | P4 | Noun | 7.04 (0.27~) | n.s. | n.s. | n.s. |
| | O1 | Noun | n.s. | n.s. | 5.80 (-0.26~) | n.s. |
| | O2 | Noun | 7.68 (0.28*) | n.s. | n.s. | n.s. |

* -- $p<0.05$; ~ -- $p<0.07$; n.s. -- non-significant

Table 10: Unique contributions to gamma area of each predictor when entered on the last step and partial correlations, separately for each VF, each channel and grammatical class (b)

| VF | Channel | Word | Length, %Vars ($r$=) | Frequency, %Vars ($r$=) | Imageability, %Vars ($r$=) | Concreteness, %Vars ($r$=) |
|---|---|---|---|---|---|---|
| R | F7 | Verb | n.s. | n.s. | n.s. | n.s. |
| | F8 | Verb | 12.34 ($0.36^{**}$) | n.s. | n.s. | n.s. |
| | C3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | C4 | Verb | 9.54 ($0.32^{*}$) | n.s. | n.s. | n.s. |
| | T5 | Verb | n.s. | n.s. | n.s. | n.s. |
| | T6 | Verb | 8.42 ($0.30^{*}$) | n.s. | n.s. | n.s. |
| | P3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | P4 | Verb | n.s. | n.s. | n.s. | 7.37 ($-0.28^{*}$) |
| | O1 | Verb | n.s. | n.s. | n.s. | n.s. |
| | O2 | Verb | n.s. | n.s. | 6.07 ($0.25^{\sim}$) | n.s. |
| L | F7 | Verb | n.s. | n.s. | n.s. | n.s. |
| | F8 | Verb | n.s. | n.s. | n.s. | n.s. |
| | C3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | C4 | Verb | n.s. | n.s. | n.s. | n.s. |
| | T5 | Verb | n.s. | n.s. | n.s. | n.s. |
| | T6 | Verb | n.s. | n.s. | n.s. | n.s. |
| | P3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | P4 | Verb | n.s. | n.s. | n.s. | 7.22 ($0.27^{*}$) |
| | O1 | Verb | n.s. | n.s. | n.s. | 10.40 ($0.34^{*}$) |
| | O2 | Verb | n.s. | n.s. | n.s. | n.s. |

$^{**}$ -- $p<0.01$; $^{*}$ -- $p<0.05$; $^{\sim}$ -- $p<0.07$; n.s. -- non-significant

#### 7.3.1.5.1.2. Regression analysis for each channel

A stepwise multiple regression analysis was performed with each predictor (word characteristics) entered in the equation last when all other predictors were controlled on the first step. Tables 10 (a) and (b) present the results of stepwise multiple regression, when each predictor was entered on the last step and partial correlations, separately for each VF, each channel and grammatical class. The results indicated that when nouns were presented to the RVF (LH), none of the word characteristics made an individual contribution to gamma area (Table 10, (a)).

Length of nouns, presented to the LVF(RH), made individual significant contribution to gamma area elicited in O2 (7.68%) and close to significant in P4 (7.04%). Frequency of nouns activated gamma oscillations in P3 (9.15%) and C4 (1.02%), and imageability made its contribution to T5 (6.61%) and O1 (5.80%) (Table 10, (a)). Note that the partial correlation between length (positive) and imageability (negative) and gamma area indicated processing difficulty strategy while partial correlation between frequency (positive) and gamma areas showed an activation pattern.

Regression analysis of verb characteristics (Table 10, (b)) when verbs were presented to the RVF(LH) showed that length made strong unique contribution to gamma variance in F8 (12.34%), C4 (9.54%) and T6 (8.42%). Note that partial correlation was positive, that is, it showed processing difficulty strategy. Imageability made marginally significant contribution to gamma area in O2 (6.07%) and concreteness -- in P4 (7.37%). When verbs were presented to the LVF (RH) only concreteness made significant contribution to the gamma area in P4 (7.22%) and O1 (10.40%).

To summarize, the analysis of verb/noun naming indicated that more lexical and conceptual verb characteristics were of importance in the RH processing when verbs were presented to the RVF(LH). When verbs were presented to the LVF (RH), only concreteness made unique contribution to the gamma variance in right parietal and left occipital regions. Lexical and conceptual characteristics of nouns were of importance in both hemisphere sites when nouns were presented to the LVF. RVF noun presentation did not produce any reliable correlation with gamma areas in any of the electrode sites.

Overall, the results indicate that different types of information were of importance in different distributed brain regions. It is worth to note that the impact of word characteristics could reflect either gamma activation or to indicate processing difficulty. It seems, that the two strategies were highly dependent on the filed of presentation and type of word characteristics.

### *7.3.1.5.2. Noun and Verb-derived Noun Naming*

#### 7.3.1.5.2.1. Regression analysis for each hemisphere

Stepwise multiple regression analysis revealed unique contribution of nouns length in letters to the RH gamma area (%Vars = 6.7; partial correlation $r$ = 0.27; $p<0.05$) when nouns were presented to the LVF(RH). VDN length made its unique contribution to RH gamma oscillations when presented to the LVF(RH) (%Vars = 15.6; partial correlation $r$ = -0.40; $p<0.01$). Note, however, that in noun case the partial correlation is positive which points to a processing difficulty gamma pattern while in the VDN case the correlation appeared to be negative that is, showed gamma activation pattern. No other significant contribution of any predictor was found. That is, presentation to the RVF(LH) caused no contribution of any predictor to elicited gamma area. This may mean that initial presentation to the LH facilitated processing to such a degree that word characteristics were not needed as a type of information for processing or, at least, their involvement was not revealed by the analysis.

#### 7.3.1.5.2.2. Regression analysis for each channel

Results of a stepwise multiple regression analysis are presented in Table 11, (a) and (b) separately for each word class, VF and channel. Analysis of noun processing (Table 11, (a)) showed significant unique frequency contribution to the gamma area variance in O1 (10.24%) when nouns were presented to the RVF(LH). Presentation to the LVF(RH) produced significant frequency contribution to the gamma variance in T5 (8.6%) and close to significant in T6 (8.41%) and P3 (8.35%). The last marginally significant was the length unique contribution to the gamma variance in O1 (9.02%) when nouns were presented to the LVF. Thus, it seems that for this subject and for the used stimuli frequency and length of nouns were of the most importance and activated gamma waves in temporal, left parietal and left occipital areas.

Analysis of VDN naming (Table 11, (b)) showed a pattern of length activation when these words were presented to the LVF(RH) Length of VDNs, presented to the LVF(RH), produced marginally significant contribution to P3 gamma activation (8.8%) and significant length contribution to P4 (20%), O1 (16.9%) and O2 (23.9%) gamma activation. Thus, length of presented to the LVF(RH) words caused difficulties in processing in occipital and parietal areas. No other significant contribution was found.

Table 11: Unique contributions to gamma area of each predictor when entered on the last step and partial correlations, separately for each VF, each channel and grammatical class

(a)

| VF | Channel | Word | Length, %Vars (*r*=) | Frequency, %Vars (*r*=) | Imageability, %Vars (*r*=) | Concreteness, %Vars (*r*=) |
|---|---|---|---|---|---|---|
| R | F7 | Noun | n.s. | n.s. | n.s. | n.s. |
| | F8 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T5 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T6 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | O1 | Noun | n.s. | 10.24 (0.32*) | n.s. | n.s. |
| | O2 | Noun | n.s. | n.s. | n.s. | n.s. |
| L | F7 | Noun | n.s. | n.s. | n.s. | n.s. |
| | F8 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T5 | Noun | n.s. | 8.60 (0.32*) | n.s. | n.s. |
| | T6 | Noun | n.s. | 8.41 (0.30~) | n.s. | n.s. |
| | P3 | Noun | n.s. | 8.35 (0.30~) | n.s. | n.s. |
| | P4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | O1 | Noun | 9.02 (-0.30~) | n.s. | n.s. | n.s. |
| | O2 | Noun | n.s. | n.s. | n.s. | n.s. |

* -- $p<0.05$; ~ -- $p<0.06$; n.s. -- non-significant

Table 11: Unique contributions to gamma area of each predictor when entered on the last step and partial correlations, separately for each VF, each channel and grammatical class

(b)

| VF | Channel | Word | Length, %Vars (*r*=) | Frequency, %Vars (*r*=) | Imageability, %Vars (*r*=) | Concreteness, %Vars (*r*=) |
|---|---|---|---|---|---|---|
| R | F7 | VDN | n.s. | n.s. | n.s. | n.s. |
| | F8 | VDN | n.s. | n.s. | n.s. | n.s. |
| | C3 | VDN | n.s. | n.s. | n.s. | n.s. |
| | C4 | VDN | n.s. | n.s. | n.s. | n.s. |
| | T5 | VDN | n.s. | n.s. | n.s. | n.s. |
| | T6 | VDN | n.s. | n.s. | n.s. | n.s. |
| | P3 | VDN | n.s. | n.s. | n.s. | n.s. |
| | P4 | VDN | n.s. | n.s. | n.s. | n.s. |
| | O1 | VDN | n.s. | n.s. | n.s. | n.s. |
| | O2 | VDN | n.s. | n.s. | n.s. | n.s. |
| L | F7 | VDN | n.s. | n.s. | n.s. | n.s. |
| | F8 | VDN | n.s. | n.s. | n.s. | n.s. |
| | C3 | VDN | n.s. | n.s. | n.s. | n.s. |
| | C4 | VDN | n.s. | n.s. | n.s. | n.s. |
| | T5 | VDN | n.s. | n.s. | n.s. | n.s. |
| | T6 | VDN | n.s. | n.s. | n.s. | n.s. |
| | P3 | VDN | 8.79 (-0.30~) | n.s. | n.s. | n.s. |
| | P4 | VDN | 19.98 (-0.45**) | n.s. | n.s. | n.s. |
| | O1 | VDN | 16.90 (-0.41*) | n.s. | n.s. | n.s. |
| | O2 | VDN | 23.92 (-0.49***) | n.s. | n.s. | n.s. |

*** -- $p<0.001$; ** -- $p<0.01$; * -- $p<0.05$; ~ -- $p<0.06$; n.s. -- non-significant

The analysis of noun/VDN naming revealed that more lexical characteristics of nouns contributed to gamma area of more posterior parts of the brain especially when nouns were presented to the LVF (RH). Gamma, elicited by VDN naming, was sensitive only to the length of the words in parietal and occipital regions and only in LVF presentation condition. VDN presentation to the RVF(LH) revealed no contribution of any of the predictors.

The results showed once again that presentation field is (may be) of a very importance in the hemispheric processing: while presentation to the RVF(LH) showed no or almost no correlations with gamma areas for both grammatical classes, LVF(RH) presentation showed some dependence of elicited gamma with word characteristics such as frequency, length and imageability. One possible explanation of these results is that in a way initial presentation to the LH facilitated the processing to a degree that none (or almost none) of the used word characteristics were required as a type of processing information reflected in elicited gamma activity. It should be noted, however, that this might concern only the used medium gamma band that is, probably, in other frequency ranges the information of word characteristics plays a visible role in the processing.

#### 7.3.1.6. Conclusion

Analysis of variance in noun/verb naming experiment indicated that gamma was sensitive to grammatical distinctions across all the electrode sites although to different degrees while noun/VDN naming experiment revealed no differences between the processing of these grammatical classes. While the first result was in agreement with the behaviour results, the later results was in contradiction to the results of RT experiment when VDN were named with considerably slower RT. No sign of SMA activation in either verb or VDN processing was obtained. The absence of such a result may be due to several reasons: (a) there was no control of verb motor associations. Although it seems that imageability rating may indirectly reflect motor associations, regression analysis did not show imageability contribution to either SMA. (b) In present experiment lateralized word naming task was used while Pulvermüller et al (1996; 1999) used lexical decision task with central presentation mode. (c) Medium gamma range was used in the present experiments as a measure while Pulvermüller et al (1996; 1999) found SMA activation in lower gamma range.

Occipital regions were activated in all grammatical class conditions thus, reflecting, probably, not (only) visual associations but a range of other involved processes (visual short-term memory, attention, and overall load on occipital regions) and, probably, sub-lexical and lexico-conceptual processing. In support of this possibility were the results of regression analysis that showed activation of verbal and conceptual characteristics in these regions that were dependent on VF and grammatical class conditions.

The results of both ANOVA and regression analysis indicated that on the one hand, frontal and supplementary motor areas were sensitive to frequency levels, on the other hand, that this sensitivity varied from site to site and from subject to subject and was dependent on VF mode of presentation. Moreover, subjects were considerably different in their behaviour. First subject (noun/verb naming) showed no VF difference and overall higher LH than RH activation in ANOVA. Second subject (noun/VDN naming) showed VF differences and the overall higher RH activation. However, both subjects showed a SMA sensitivity to frequency levels of less imageable words. Friez & Petersen (1998) proposed that motor cortex is involved not only in pure motoric aspects of speech but also in the process of transformation from phonological to articulatory representation. It seems that this suggestion fits in a way the SMA sensitivity to frequency levels. That is, phonological transformation is (may be) influenced by the frequency of a word.

It seems that ANOVA and regression analysis revealed different sides of one process. ANOVA showed gamma sensitivity to conditions in terms of both processing advantage and processing strategies. Regression analysis showed gamma sensitivity in terms of both word properties involvement in the processing and processing strategies. Moreover, regression analysis showed that absence of an involvement of word characteristics in a process may be an indication of facilitative processing. For example, RVF(LH) noun presentation did not activate/contribute to any area by any noun characteristics, and verb presentation to the RVF(LH) showed length and concreteness involvement in the processing of RH. That is, nouns were processed equally easy by both hemispheres in this VF condition while verbs were processed easier in the left than in the right hemisphere. This assumption is in agreement with behavioural studies (e.g., Sereno, 1999) which suggest no lateralization in noun processing and LH advantage for verb processing. Probably, the assumption may be tested in other frequency range, namely, in the alpha range. That is, alpha should show high activation in the case of easy and, in a way, routine processing and show low activation in the case of hard and resource demanding processing.

From other side, length of the words activated mainly posterior areas that reflected initial visual processing which is in agreement of some findings that suggest that occipito-temporal regions are involved in pre-lexical coding (Fiebach et al, 2002). However, length of verbs was of importance in frontal, motor and temporal parts of the right cortex with RVF (LH) presentation, suggesting that RH was involved in sub- and lexical processing of the verbs. In addition, in this VF condition more posterior parts of the cortex were involved in conceptual processing. Verb presentation to the LVF(RH) activated only conceptual characteristics in posterior parts (parietal and occipital) suggesting that posterior pats may be involved in conceptual processing. Recall also that both subjects showed an activation in right parietal area along with the sensitivity to conceptual factor (imageability). As Levelt et al. (1998) showed, right parietal region was involved in lemma selection in picture naming task that is, this region was activated in response to conceptual and grammatical information processing.

Overall, the results showed that different parts of the brain participated differently in the whole process, showing sensitivity to and involvement of different types of word characteristics in the processing within the same areas. That is, the same areas responded differently to various conditions showing, probably, the degree of the load and capacities of both hemispheres.

An intriguing result is that gamma as a measure could reflect both activation and processing difficulty strategies. Although the data of two subjects are obviously not enough to insure this power of gamma, it seems that it could be a promising area to study.

### *7.3.2. Picture Naming*

In order to have more information about processing, here ANOVA analysis was also conducted. Frequency of the items were controlled and imageability was varied with two levels: low and high. Table 12 presents descriptive statistics of chosen for the ANOVA items out of the whole data set. Although imageability levels of produced nouns were very close, t-test revealed significant differences between low and high mean imageability of nouns as well as of verbs and verb-derived nouns.

For the analysis with hemispheres (LH, RH) as one of the independent variables, the data were averaged by items over channels.

Stepwise multiple regression analysis was done on the whole collected data set. Regression analysis, done separate for each hemisphere, was done on data preliminary averaged by hemispheres.

#### 7.3.2.1. Data Reduction

##### 7.3.2.1.1. Object (Noun) and Action (Verb) naming experiments

Trials on which no response was registered or response with a picture name/word that was absent in the word characteristics database (3.6% for object naming and 28.7% for action naming task) were excluded

Table 12: Means and SDs of selected for ANOVA analysis target word characteristics for picture naming experiments separately for Object (noun) and Action (verb) naming and Object (noun) and VDN naming tasks

| | | Mean (SD) | Low<br>M (SD) | High<br>M (SD) |
|---|---|---|---|---|
| N | Letters | 5.3 (1.4) | | |
| O | Frequency | 5.0 (0.3) | | |
| U | Imageability | 6.3 (0.3) | 6.0 (0.1) | 6.5 (0.1) |
| N | Concreteness | 6.0 (0.4) | | |
| V | Letters | 6.4 (2.2) | | |
| E | Frequency | 5.1 (0.3) | | |
| R | Imageability | 5.5 (0.5) | 5.1 (0.4) | 5.9 (0.3) |
| B | Concreteness | 4.5 (0.5) | | |
| N | Letters | 5.3 (1.5) | | |
| O | Frequency | 4.6 (0.3) | | |
| U | Imageability | 6.2 (0.2) | 6.0 (0.1) | 6.4 (0.1) |
| N | Concreteness | 6.1 (0.4) | | |
| V | Letters | 7.3 (1.5) | | |
| D | Frequency | 4.7 (0.3) | | |
| N | Imageability | 5.5 (0.7) | 4.8 (0.5) | 6.0 (0.3) |
| | Concreteness | 4.6 (0.5) | | |

from the analyses. In addition, trials or data of separate channels with bad quality of a signal (0.7% and 0.2%, respectively, for only object naming task) were also removed. Thus, a total of 95.7% (object naming) and 71.3% (action naming) of the originally collected EEG data were included in further analyses.

#### 7.3.2.1.2. Object (Noun) and VDN naming experiments

Similarly, trials on which no response was produced or response with a picture name/word that was absent in the word characteristics database (5% for object naming and 25% for VDN naming task) were excluded from the analyses. Trials or data of separate channels with bad quality of a signal (0.7% and 0.3%, respectively, for only object naming task) were also removed. Thus, a total of 94.3% (object naming) and 75% (VDN naming) of the originally collected EEG data were included in further analyses.

### 7.3.2.2. Object (Noun) and Action (Verb) Naming

#### 7.3.2.2.1. Analysis of variance with hemispheres as one of the independent variables

A 2 (VF) x 2 (Hemispheres) x 2 (Grammatical Class) x (Imageability) analysis on gamma area revealed two significant main effects. A main effect of VF ($F_{(1,102)}$=4.73; p<.05) showed that picture presentation to the LVF caused smaller gamma area (0.81) than presentation to the RVF (0.90). A main effect of hemispheres ($F_{(1,102)}$=6.85; p<.05) revealed that gamma area in the LH (0.91) was larger than in the right one (0.81). No other main effects were obtained. Two marginally significant interactions were found. An interaction between VF and Imageability ($F_{(1,102)}$=3.87; p<.052) is shown in Figure 12. Post hoc revealed significant differences between mean gamma area elicited by produced low imageable responses when pictures were presented to the LVF and the three other means. Thus, high imageable response words as well as low imageable with pictures presented to the RVF, elicited higher gamma activation than low imageable responses to pictures presented to the LVF. Note that pictures, presented to the LVF caused gamma activation pattern. An interaction between Grammatical class and Hemisphere ($F_{(1,102)}$=3.73; p<.056) is presented in Figure 13. It is seen, that object naming in two hemispheres and action naming in the RH elicited insignificantly from each other gamma areas that were significantly smaller than gamma area produced by action naming in LH. Thus, object naming was processed equally in both hemispheres in terms of elicited gamma waves while action naming activated LH more than the right one.

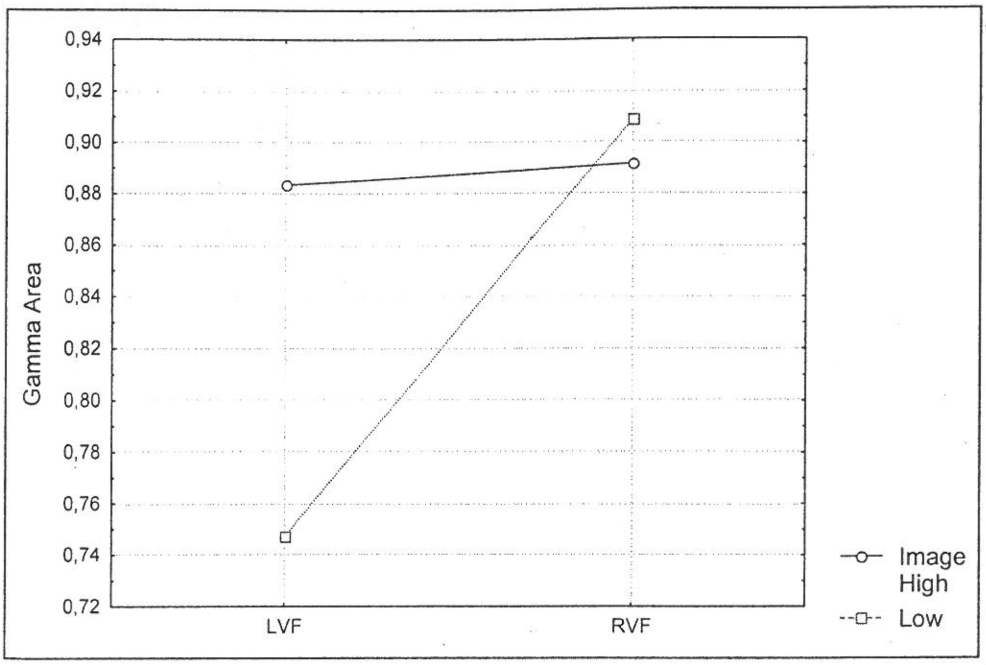


Figure 12. VF by Imageability interaction, PN

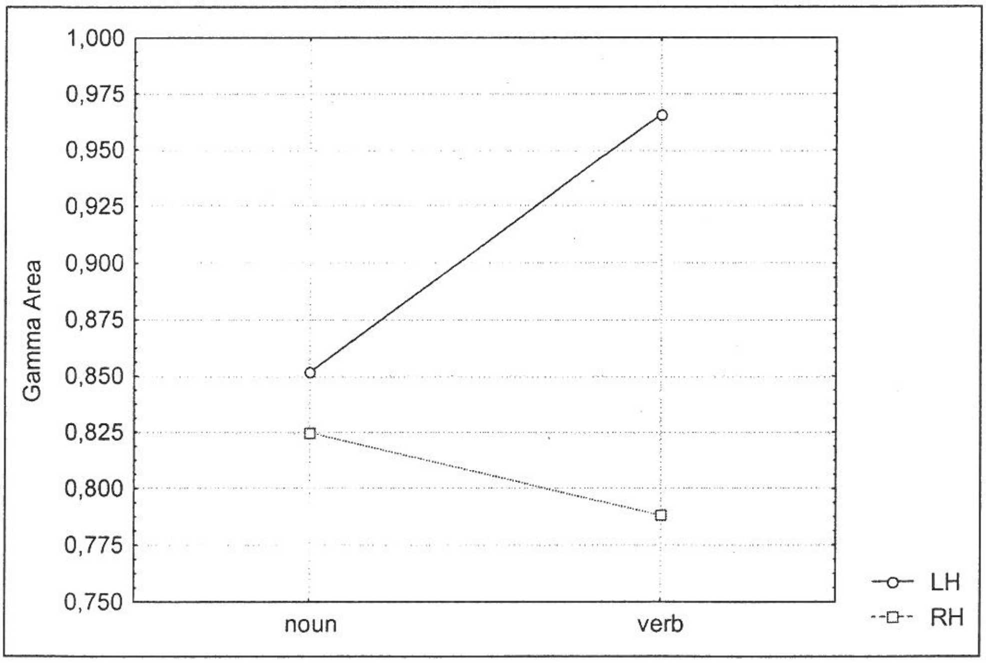


Figure 13. Hemisphere by Grammatical class interaction, PN

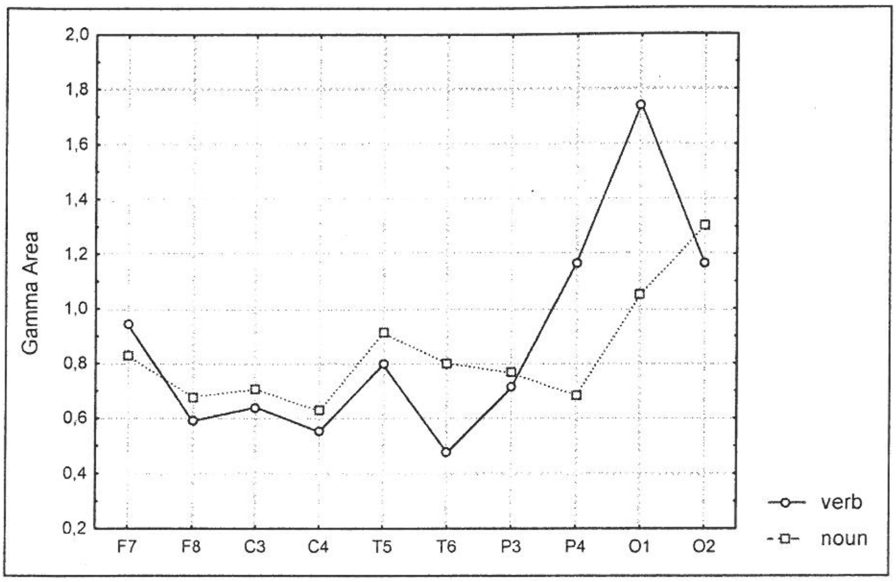


Figure 14. Channel by Grammatical class interaction, PN

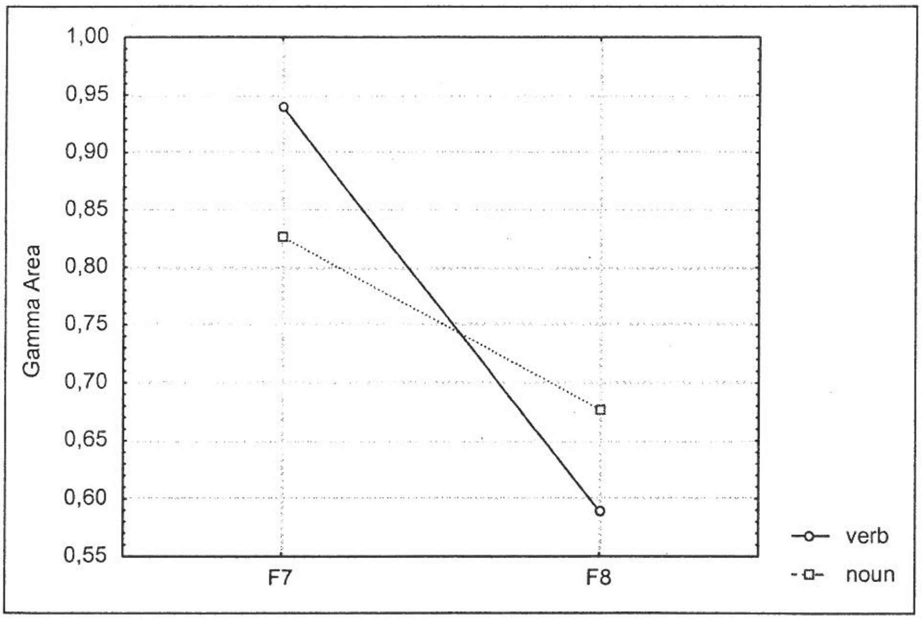


Figure 15. Channel by Grammatical class interaction, PN

#### 7.3.2.2.2. Analysis of gamma oscillation in all 10 channels

Analysis with 10 channels revealed significant main effect of Channels ($F_{(1,504)}$=9.14; p<.01) and significant interaction ($F_{(9,504)}$=14.31; p=.00) between Channels and Grammatical class (Figure 14). It is seen that the main gamma activation was in O1 and O2, P4 (in the case of action naming), T5 and F7. Note that here again was no activation in SMA areas (C3 and C4) in the case of action naming. Thus, probably, the task was too complex and, probably, high cognitive load suppressed motor associations. Gamma activation in occipital region may reflect short-term visual memory load.

#### 7.3.2.2.3. Analysis of gamma oscillation in pairs of channels

In order to reveal how each variable influenced gamma oscillations in each pair of channels, a separate analysis was done for each channel pair as an independent variable.

*F7, F8* A 2 (Imageability) x 2 (VF) x 2 (Grammatical class) x 2 (Channel) analysis found a single main effect of Channel ($F_{(1,96)}$=57.90; p=.00). Larger gamma area was found in F7 (0.88) that in F8 (0.63). A significant Channel by Grammatical class interaction ($F_{(1,96)}$=9.37; p<.01) is shown in Figure 15. Significant differences were found across all the means. Thus, action naming elicited more active gamma in F7 and less active gamma in F8 than object naming. Note that the same trend was observed in word naming task (Figure 7). No other significant interactions were found.

*C3, C4* Two main significant effects were found. A main effect of Channel ($F_{(1,102)}$=12.02; p<.001) showed that gamma area in C3 (0.68) was larger that in C4 (0.59). A main effect of Grammatical class ($F_{(1,102)}$=8.44; p<.01) revealed that action naming in these areas elicited less gamma activation (0.59) than object naming (0.67). An interaction between Imageability and VF ($F_{(1,102)}$=6.25; p<.05) is shown in Figure 16. Post hoc analysis found that low imageable response words elicited significantly larger gamma area when pictures were presented in RVF than in the rest three, insignificant from each other by mean gamma area conditions. Note, that while gamma areas of high imageable response words were not sensitive to VF, low imageable response words showed different activation patterns depending on VF: RVF picture presentation showed processing difficulty strategy, and LVF picture presentation caused an activation gamma strategy in SMA. No other significant main effect or interaction was found. Thus, it seems that SMA was concerned not with motor associations but rather with imageability levels and VFs.

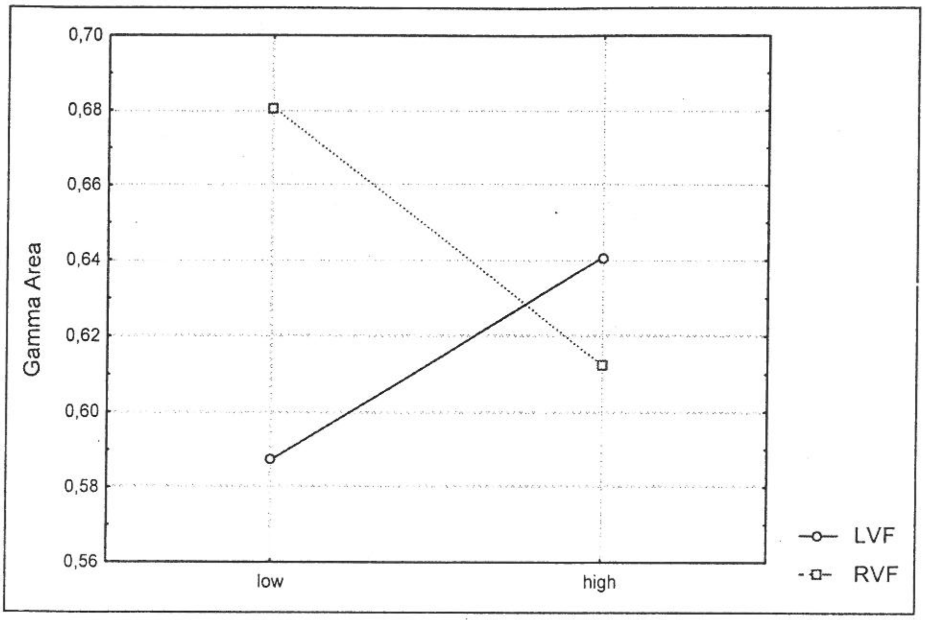


Figure 16. Imageability by VF interaction, PN

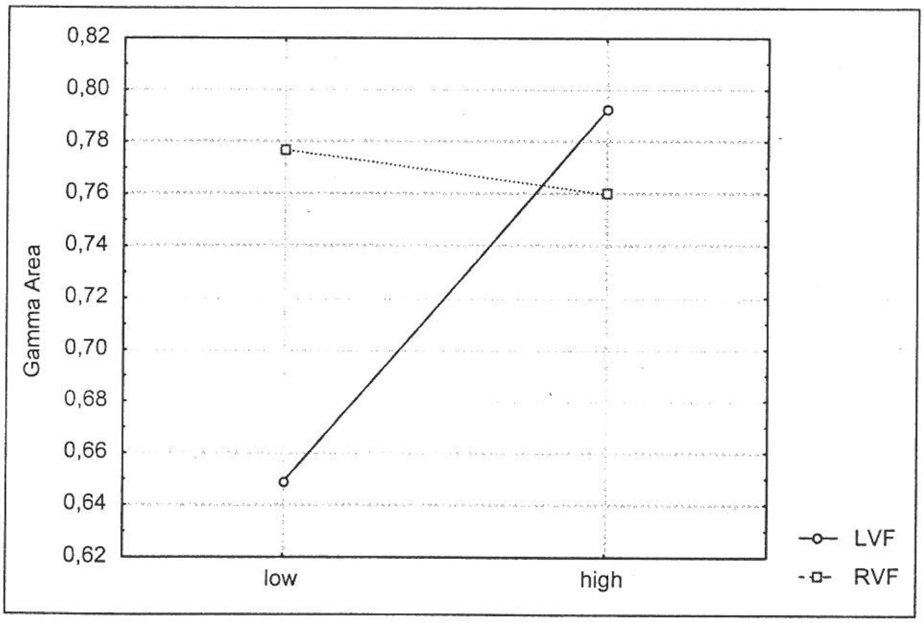


Figure 17. Imageability by VF interaction, PN

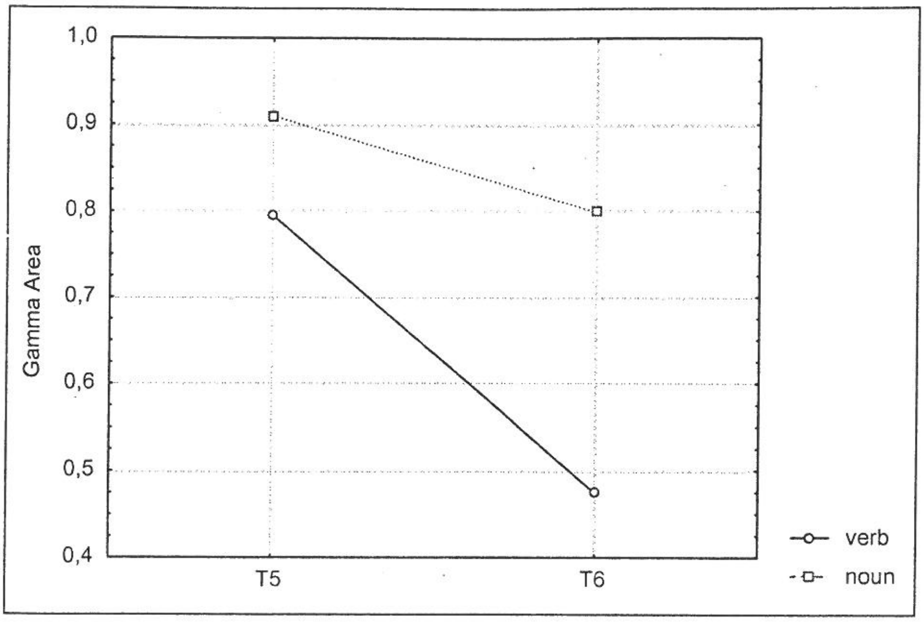


Figure 18. Channel by Grammatical class interaction, PN

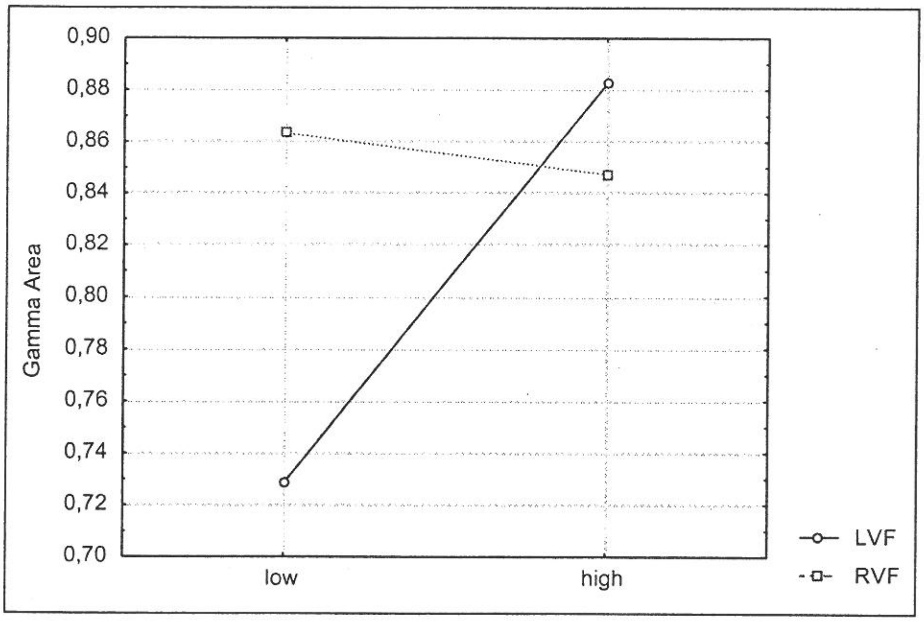


Figure 19. Imageability by VF interaction, PN

*T5, T6* Two significant main effects were found. A main effect of Channel ($F_{(1,102)}$=34.56; p=.00) showed that gamma area in T5 was larger (0.85) than in T6 (0.64). A main effect of Grammatical class ($F_{(1,102)}$=35.89; p=.00) found that produced nouns elicited larger gamma area (0.85) than produced verbs (0.63). An interaction between VF and Imageability ($F_{(1,102)}$=4.77; p<.05) is shown in Figure 17. Post hoc analysis revealed significant differences between mean gamma area of low imageable produced words when pictures were presented to the LVF and the three other means. Here again, high imageable responses were not sensitive to the VF while low imageable responses were. Also, while pictures in RVF elicited same gamma activation, pictures presented in the LVF caused an activation gamma behavior, i.e., higher imageable picture names elicited higher gamma than lower imageable. A significant interaction between Grammatical class and Channel ($F_{(1,102)}$=8.18; p<.01) is presented in Figure 18. Significant differences were found across all the means except nouns in T6 and verbs in T5. Thus, the interaction just confirmed the obtained main effect of Channel for both grammatical classes. No other significant interactions were revealed.

*P3, P4* The analysis found two significant main effects. A main effect of Channel ($F_{(1,102)}$=18.99; p=.00) showed that gamma area in P3 was smaller (0.74) that in P4 (0.92). A main effect of Grammatical class ($F_{(1,102)}$=25.52; p=.00) found that action naming elicited more active gamma (0.94) than object naming (0.72). A significant interaction between Imageability and VF ($F_{(1,102)}$=3.99; p<.05) is shown in Figure 19. Here again, as in T5 and T6 areas, high imageable picture names were not sensitive to the presentation field while low imageable were. Also, LVF presentation caused an activation pattern of gamma behavior similar to that in temporal areas.

Imageability by Grammatical class interaction ($F_{(1,102)}$=3.95; p<.05) is shown in Figure 20. Object naming was not sensitive to the imageability levels while action naming was. As a whole, elicited gamma by action naming was significantly larger than gamma, elicited by object naming. Note, that here gamma showed an activation pattern: higher imageable response verbs produced larger than lower imageable, gamma areas. At the same time, object naming as a task was easier than action naming and here it showed processing difficulty strategy. Indifference of gamma waves elicited by object naming to the imageability levels may be explained by quite high overall imageability of produced names of the objects. So, in spite of found by t-test difference of noun imageability mean ratings, gamma oscillations were the same in terms of their area in response to overall high imageable named objects.

An interaction between Grammatical class and Channel ($F_{(1,102)}$=39.91; p=.00) is presented in Figure 21. In P3 picture naming elicited indifferent to the task gamma areas while in P4 action naming caused more

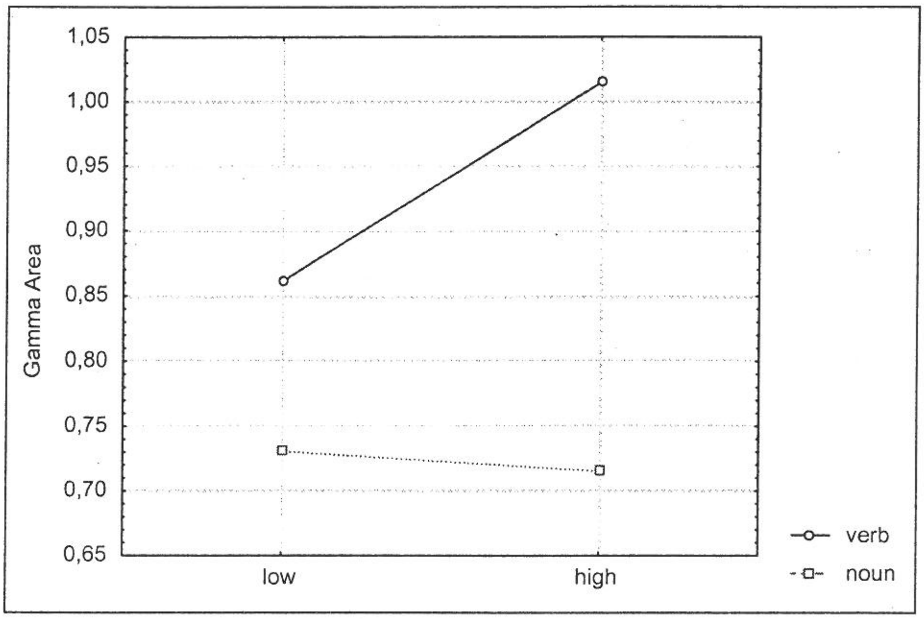


Figure 20. Imageability by Grammatical class interaction, PN

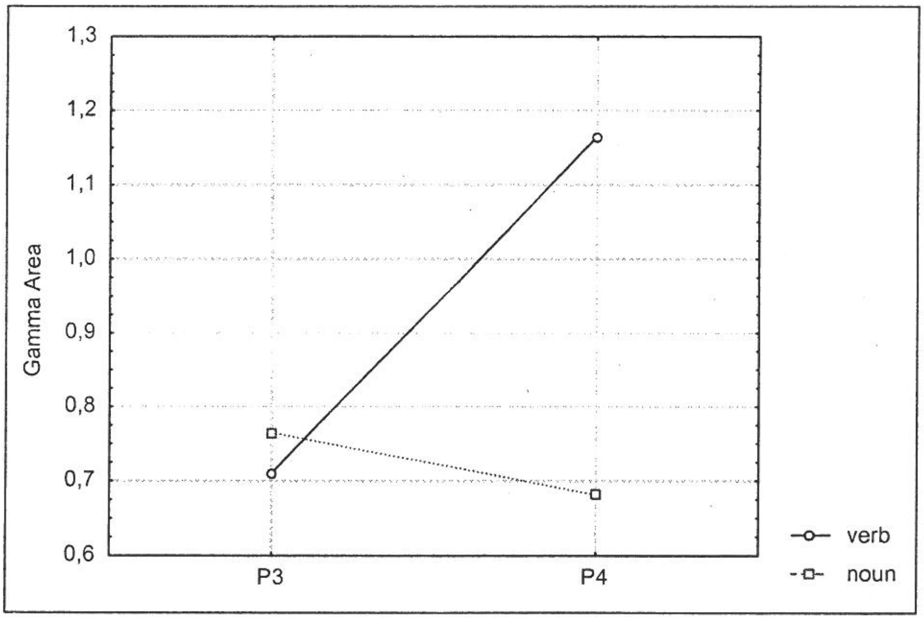


Figure 21. Channel by Grammatical class interaction, PN

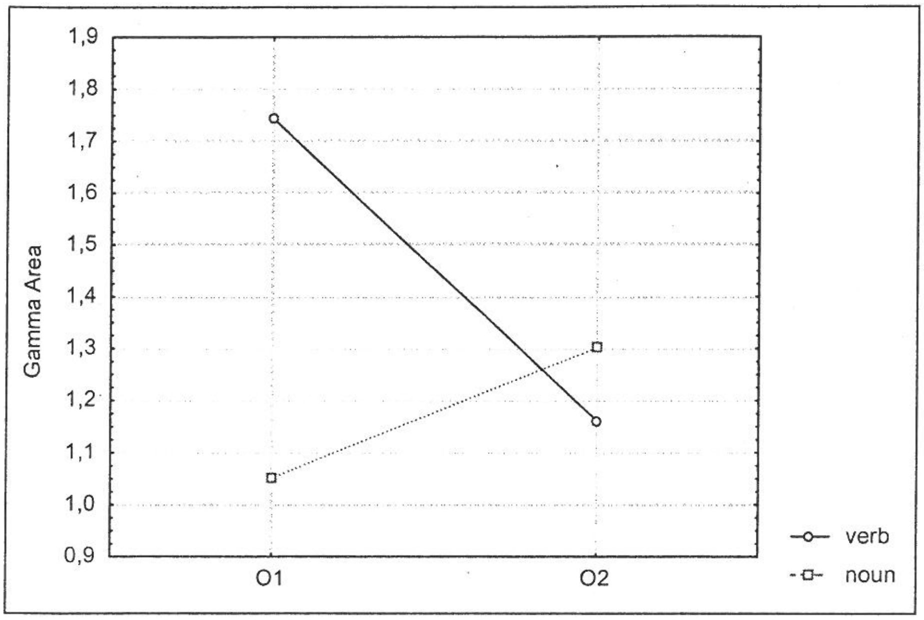


Figure 22. Channel by Grammatical class interaction, PN

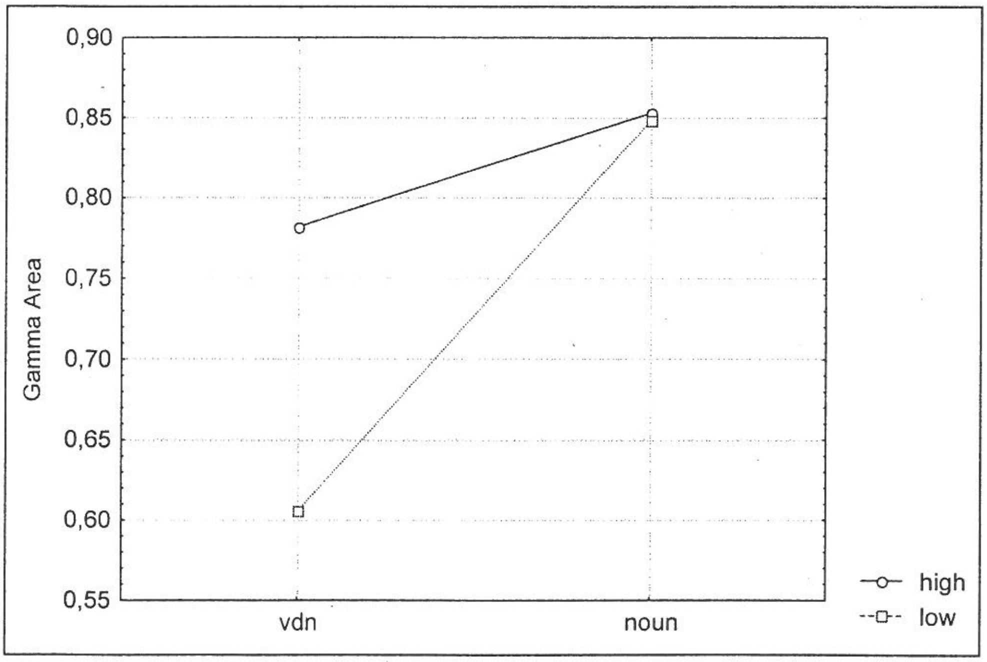


Figure 23. Imageability by Grammatical class interaction, PN

active gamma than object naming in P4 or the two picture naming tasks in P3. No other significant interactions were found.

*O1, O2* A main effect of VF ($F_{(1,102)}$=5.56; p<.05) showed that pictures presented to the LVF, elicited smaller gamma area (1.19) than pictures, presented to the RVF (1.44). A main effect of Grammatical class ($F_{(1,102)}$=6.41; p<.0128) revealed that action naming elicited larger gamma area (1.45) than object naming (1.18). No other significant main effect was found.

The only found significant interaction between Channel and Grammatical class ($F_{(1,102)}$=14.55; p<.001) is presented in Figure 22. Surprisingly, here the action naming pattern of activation appeared to be different: it was not in the RH (O2) as it could be supposed after such an activation in P4 but in the left occipital area (though see Figure 14).

Overall, it seems that in left frontal and right temporal and parietal and left occipital areas action naming elicited more active gamma than object naming. SMA and temporal regions appeared to be sensitive to VF and imageability levels. Parietal areas were not sensitive to VF but sensitive to grammatical class and imageability. Analysis on occipital areas showed gamma dependency on VF as well as on grammatical class.

### 7.3.2.3. Object (Noun) and VDN naming

#### 7.3.2.3.1. Analysis of variance with hemispheres as one of the independent variables

A 2 (VF) x 2 (Hemispheres) x 2 (Grammatical Class) x (Imageability) analysis on gamma area revealed two significant main effects. A main effect of Imageability ($F_{(1,160)}$=7.97; p<.01) showed that pictures that elicited responses with high imageability produced larger gamma area (0.82) than pictures that elicited names with low imageability (0.73). Thus, here gamma oscillations were more active with higher imageable response words that with lower. A main effect of Grammatical class ($F_{(1,160)}$=23.79; p<.00) revealed that gamma waves elicited by object naming were more active (0.85) than gamma waves elicited by VDN picture naming (0.69). Again, gamma behavior showed an activation strategy since object naming task was considerably easier that VDN naming task.

A significant interaction between Imageability and Grammatical class ($F_{(1,160)}$=7.10; p<.01) is shown in Figure 23. Pictures that were named as low imageable VDNs elicited significantly smaller gamma area than gamma in the three other conditions. Thus, high imageable VDN responses and object naming response produced higher gamma activation than low imageable VDN responses.

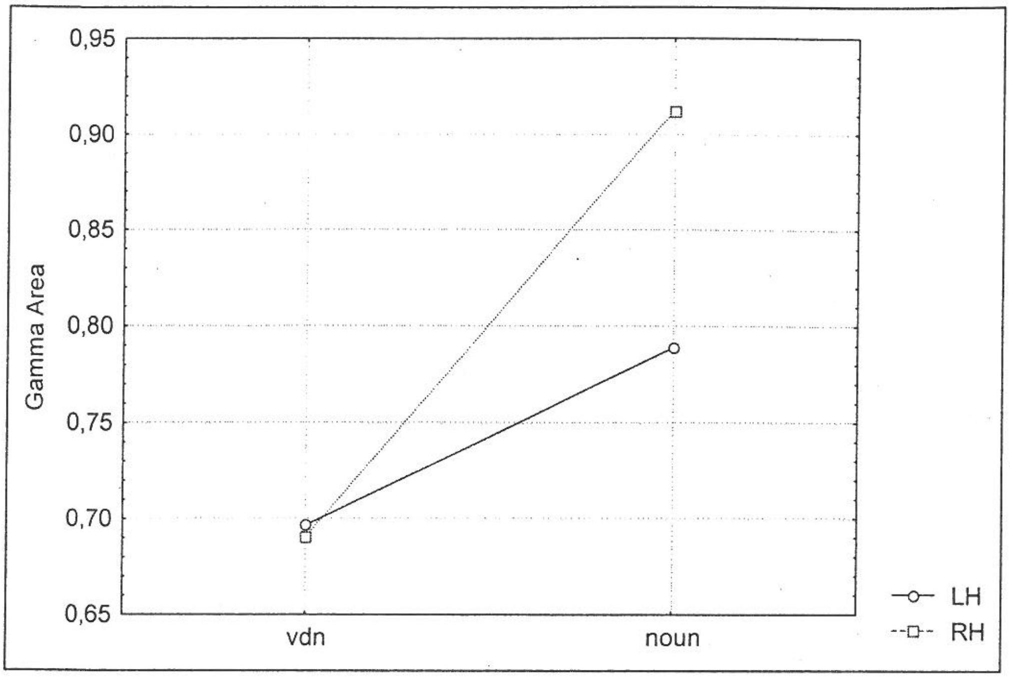


Figure 24. Hemisphere by Grammatical class interaction, PN

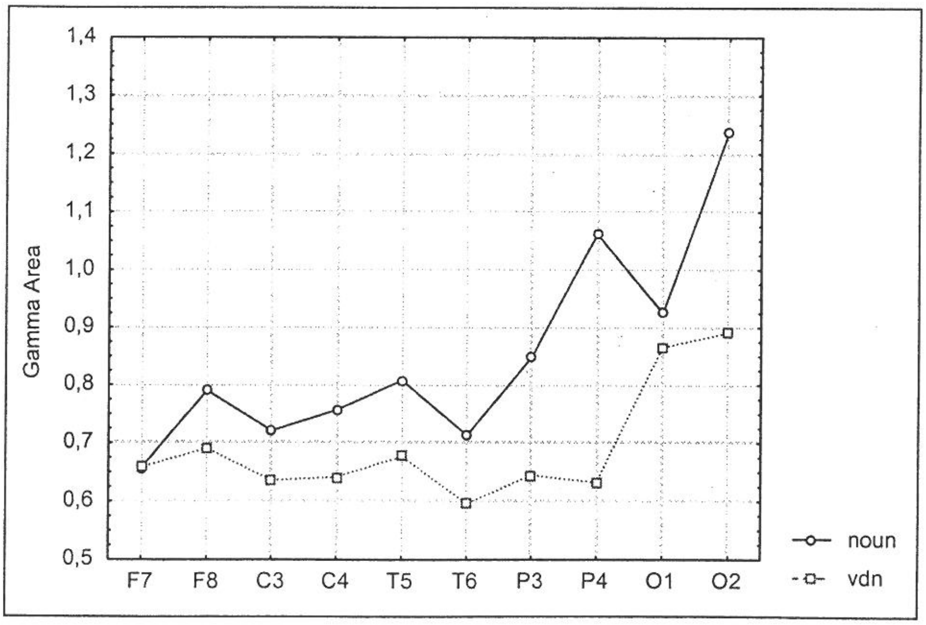


Figure 25. Channel by Grammatical class interaction, PN

An interaction between Hemisphere and Grammatical class ($F_{(1,160)}$=4.04; p<.05) is presented in Figure 24. Significant differences were found across all the mean points except for mean gamma areas elicited by VDN naming task. Thus, VDN picture naming was processed equally by both hemispheres while object naming elicited stronger gamma activation in RH than in left one. No other significant effect or interactions were found.

**7.3.2.3.2. Analysis of gamma oscillations in all 10 channels**

Analysis with 10 channels revealed significant main effect of Channels ($F_{(9,788)}$=24.00; p=0.0) and significant interaction ($F_{(9,788)}$=6.41; p=.00) between Channels and Grammatical class (Figure 25). It is seen that object naming activated gamma waves generally stronger than VDN picture naming except for F7 and O1 channels. Note the elicited high gamma activation in right parietal and occipital lobes for object naming. Probably, imageability of the response words play a role here. SMA areas elicited more active gamma in object naming than in VDN action naming task. Thus, with these tasks, stimuli and subject it seems, that SMA was responding not to motor associations (action semantics) but to some other factors.

**7.3.2.3.3. Analysis of gamma oscillations in pairs of channels**

The results of a separate 2 (Imageability) x 2 (VF) x 2 (Grammatical class) x 2 (Channel) analysis are presented below.

*F7, F8* A main effect of Imageability ($F_{(1,159)}$=6.39; p<.05) showed that .high imageable response words elicited stronger gamma activation (0.74) than low imageable (0.66). A significant main effect of Channel ($F_{(1,159)}$=7.12; p<.01) revealed that gamma area was larger in F8 (0.74) than in F7 (0.66). No other significant main effects were found.

The only significant interaction between Imageability and Grammatical class ($F_{(1,159)}$=12.26; p<.001) is presented in Figure 26. Object naming along with VDN naming with high imageable responses elicited significantly higher gamma activation than low imageable VDN responses. It seems that not grammatical class but rather imageability levels were important.

*C3, C4* Two significant main effects were found. A main effect of Imageability ($F_{(1,160)}$=5.95; p<.05) showed that responses with higher imageable word ratings elicited stronger gamma activation (0.73) than responses with lower imageable ratings (0.65). A main effect of Grammatical class ($F_{(1,160)}$=10.38;

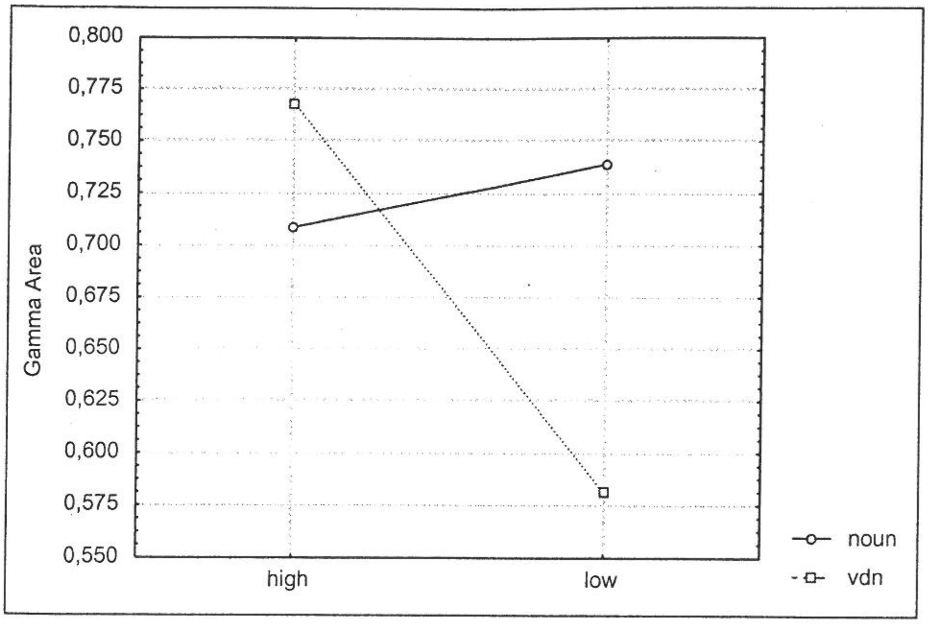


Figure 26. Imageability by Grammatical class interaction, PN

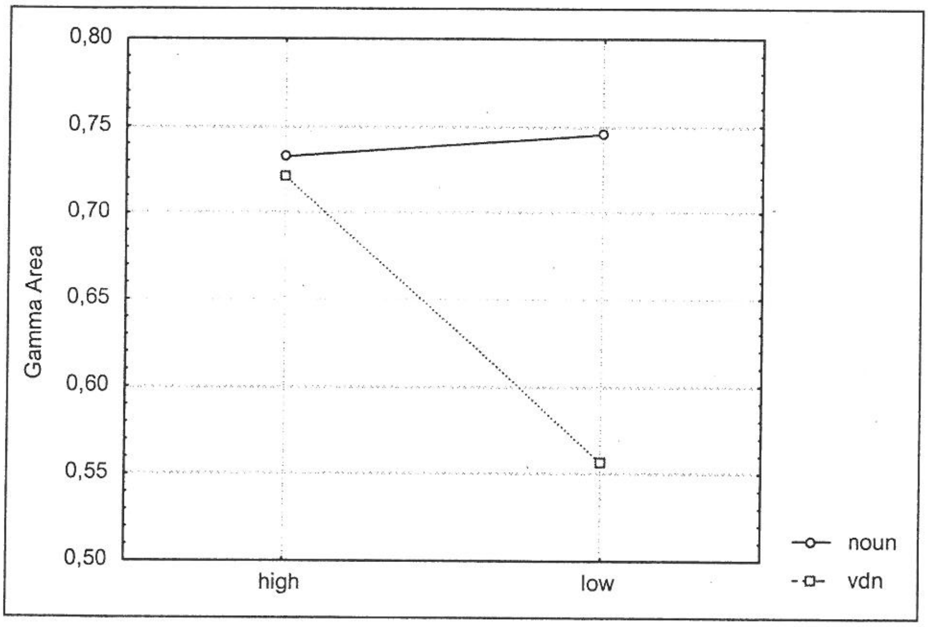


Figure 27. Imageability by Grammatical class interaction, PN

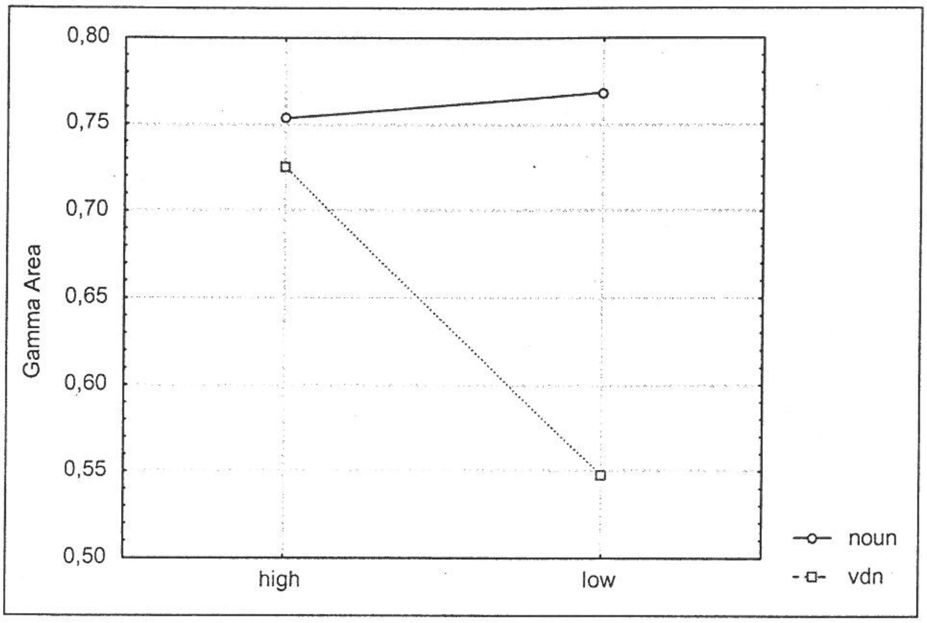


Figure 28. Imageability by Grammatical class interaction, PN

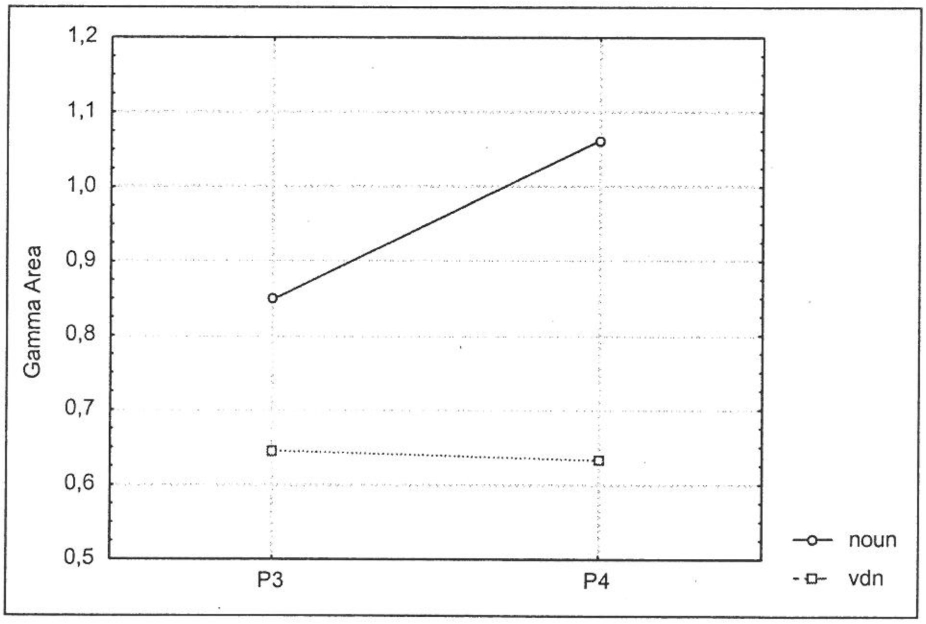


Figure 29. Channel by Grammatical class interaction, PN

p<.01) revealed that object naming elicited larger gamma area (0.74) than VDN picture naming (0.64). No difference between channels was revealed.

A significant interaction between Imageability and Grammatical class ($F_{(1,160)}$=8.17; p<.01) is presented in Figure 27. As in previous interaction (Figure 26), object and VDN naming with high imageable responses produced higher gamma activation than VDN responses with low imageable words. No other significant interactions were found. Thus, the pattern of activation in SMA appeared to be the same as in frontal areas.

*T5, T6* Three main significant effects were found. A main effect of Imageability ($F_{(1,160)}$=5.66; p<.05) again showed that responses with high imageable rating elicited stronger gamma activation (0.74) than responses with low imageable rating (0.66). A main effect of Channel ($F_{(1,160)}$=6.57; p<.05) showed that gamma activation in T5 was higher (0.74) than in T6 (0.65). A significant main effect of Grammatical class ($F_{(1,160)}$=13.22; p<.0004) revealed that object naming (0.76) activated gamma oscillations stronger than VDN naming (0.64).

A significant interaction between Imageability and Grammatical class ($F_{(1,160)}$=7.93; p<.01) is shown in Figure 28. Similarly to all found Imageability x Grammatical class interactions, object and VDN naming with higher imageability response words produced stronger gamma activation than VDN responses with lower imageability response words. No other significant interactions were found.

*P3, P4* A main effect of Imageability ($F_{(1,160)}$=8.73; p<.01) again showed that high imageable responses (0.85) elicited stronger gamma activity than low imageable responses (0.74). A main effect of Channel ($F_{(1,160)}$=7.00; p<.01) revealed that gamma activation in right parietal area was higher (0.85) than in the left one (0.75). Finally, a main effect of Grammatical class ($F_{(1,160)}$=69.79; p=.00) showed that object naming in these areas elicited considerably stronger gamma activation (0.96) than VDN naming (0.64).

A significant interaction between Grammatical class and Channel ($F_{(1,160)}$=8.89; p<.01) is presented in Figure 29. It showed that VDN naming elicited the same gamma oscillations in the two parietal areas while object naming produced more active gamma in P4 than in P3. Post hoc analysis revealed significant differences between mean gamma areas elicited by object and VDN naming. No other significant interactions were found.

*O1, O2* Three significant main effects were revealed. A main effect of Imageability ($F_{(1,149)}$=6.25; p<.05) showed again, that high imageable response words elicited more active gamma (1.04) than less imageable (0.92). A main effect of Channel ($F_{(1,149)}$=11.01; p<.01) found that gamma activation

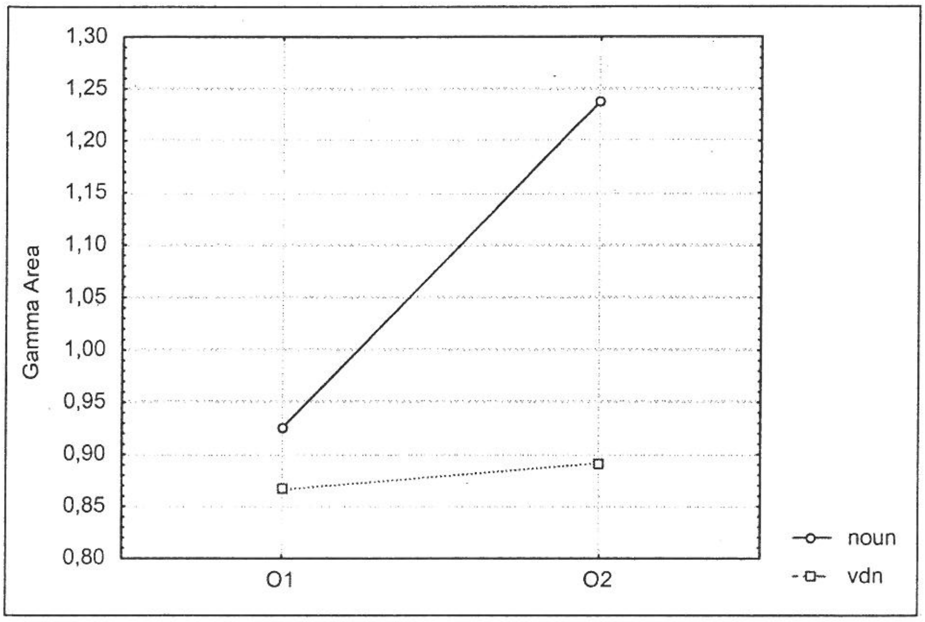


Figure 30. Channel by Grammatical class interaction, PN

was stronger in O2 (1.06) that in O1 (0.90). A main effect of Grammatical class ($F_{(1,149)}=15.91$; $p<.0001$) showed that object naming elicited more active gamma (1.08) than VDN naming (0.88).

The only found significant interaction between Grammatical class and Channel ($F_{(1,149)}=7.94$; $p<.01$) is shown in Figure 30. It is clearly seen that object naming in O2 elicited more active gamma oscillations than in the three other conditions.

Thus, no VF differences were obtained. High imageable response words independently on grammatical class elicited more active gamma oscillations in all areas. So, high imageable VDN responses elicited as active gamma as elicited overall high imageable object naming response words.

#### 7.3.2.4. Summary of the Results

In action and object naming experiments the results revealed that LH produced more active gamma than the right one. Object naming elicited equal gamma activation in both hemispheres while action naming elicited more active gamma in LH than in RH. Here again, as in word naming task, no SMA was activated in response to action naming. As in word naming task, frontal areas processed action and object naming differently: action naming elicited more active gamma in F7 and less active in F8 than object naming. SMAs appeared to be sensitive to VF and low imageability response words and produced different strategy patterns in terms of gamma. Temporal areas were as sensitive to VF and low imageability as were SMAs. Right parietal region, as in word naming task, was more active than the left one. In addition, analysis showed that in parietal region object naming processing was not sensitive to imageability levels (which can be explained by generally high both levels) while action naming showed more activation with high imageable response verbs. Moreover, action naming activated right parietal area more than the left parietal area and than object naming in these regions. Occipital areas showed VF effect: pictures presented to the LVF, elicited smaller gamma area than picture presented to the RVF. Action naming activated left occipital region more than the right one and than object naming in both occipital areas.

In object and VDN naming gamma showed an activation pattern with high imageable response words and with object naming in comparison to a more complex VDN naming task. In addition, VDN naming produced equal in both hemispheres gamma oscillations while object naming activated RH more than LH in terms of gamma. Frontal areas were sensitive to imageability. Moreover, right frontal area appeared to be more active than the left one. Frontal areas as well as SMA and temporal, showed the same pattern of activation processing: high imageable objects and high imageable VDN elicited higher gamma than low imageable VDNs. Right parietal region showed more active gamma in object processing comparing to the left parietal and to the VDN naming processing. Similar pattern was observed in occipital regions.

### 7.3.2.5. Regression Analysis with Predictors as Variables

#### *7.3.2.5.1. Object (Noun) and Action (Verb) naming*

##### 7.3.2.5.1.1. Regression Analysis for Each Hemisphere

Regression analysis done on gamma area separately for each grammatical class, each VF and each hemisphere did not reveal any significant result.

##### 7.3.2.5.1.2. Regression Analysis for Each Channel

Regression analysis results are summarized in Table 13 (a) and (b). When objects were presented to the RVF, none of the predictors made a significant contribution to the gamma variance (cf. Table 13, (a)). The only marginally significant contribution was that of length of the produced nouns in P4 (5.6%). Note that partial correlation was negative ($r$ = -0.24) that is, shorter words produced more active gamma than longer words. In LVF presentation condition, regression analysis revealed unique contribution of length (6.0%) and frequency to gamma oscillations in O2 (7.4%) and concreteness in T6 (5.8%). Interestingly, length in O2 that is, exactly in the presentation area, showed simultaneously gamma activation elicited by the length of produced nouns and processing difficulty influenced by frequency of the words.

Regression analysis results for action naming are presented in Table 13, (b). Contribution to gamma variance in T5 was made by imageability factor (7.8%) when action pictures were presented to the LVF. No other significant or close to significant contribution was found. In RVF condition frequency made a significant contribution to gamma variance in T6 (9.3%), imageability – in F7 (8.8%), and concreteness – in O2 (8.5%). Note, that only concreteness showed an activation pattern in O2 (positive partial correlation).

Overall, though no significant results were revealed in the analysis by hemispheres, channel separate analysis obtained few significant contributions. It seems that more verbal characteristics made contribution to object naming processing and more conceptual characteristics contributed to action naming processing.

Table 13: Unique contributions to gamma area of each predictor when entered on the last step and partial correlations, separately for each VF, each channel and grammatical class for picture naming task

(a)

| VF | Channel | Word | Length, %Vars ($r$=) | Frequency, %Vars ($r$=) | Imageability, %Vars ($r$=) | Concreteness, %Vars ($r$=) |
|---|---|---|---|---|---|---|
| R | F7 | Noun | n.s. | n.s. | n.s. | n.s. |
| | F8 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T5 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T6 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P4 | Noun | 5.6 (-0.24~) | n.s. | n.s. | n.s. |
| | O1 | Noun | n.s. | n.s. | n.s. | n.s. |
| | O2 | Noun | n.s. | n.s. | n.s. | n.s. |
| L | F7 | Noun | n.s. | n.s. | n.s. | n.s. |
| | F8 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | C4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T5 | Noun | n.s. | n.s. | n.s. | n.s. |
| | T6 | Noun | n.s. | n.s. | n.s. | 5.8 (-0.24~) |
| | P3 | Noun | n.s. | n.s. | n.s. | n.s. |
| | P4 | Noun | n.s. | n.s. | n.s. | n.s. |
| | O1 | Noun | n.s. | n.s. | n.s. | n.s. |
| | O2 | Noun | 6.0 (-0.26*) | 7.4 (-0.39*) | n.s. | n.s. |

* -- p<0.05; ~ -- p<0.06; n.s. -- non-significant

Table 13: Unique contributions to gamma area of each predictor when entered on the last step and partial correlations, separately for each VF, each channel and grammatical class for picture naming task

(b)

| VF | Channel | Word | Length, %Vars (*r*=) | Frequency, %Vars (*r*=) | Imageability, %Vars (*r*=) | Concreteness, %Vars (*r*=) |
|---|---|---|---|---|---|---|
| R | F7 | Verb | n.s. | n.s. | 8.8 (-0.31*) | n.s. |
| | F8 | Verb | n.s. | n.s. | n.s. | n.s. |
| | C3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | C4 | Verb | n.s. | n.s. | n.s. | n.s. |
| | T5 | Verb | n.s. | n.s. | n.s. | n.s. |
| | T6 | Verb | n.s. | 9.3 (-0.31*) | n.s. | n.s. |
| | P3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | P4 | Verb | n.s. | n.s. | n.s. | n.s. |
| | O1 | Verb | n.s. | n.s. | n.s. | n.s. |
| | O2 | Verb | n.s. | n.s. | n.s. | 8.5 (0.30*) |
| L | F7 | Verb | n.s. | n.s. | n.s. | n.s. |
| | F8 | Verb | n.s. | n.s. | n.s. | n.s. |
| | C3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | C4 | Verb | n.s. | n.s. | n.s. | n.s. |
| | T5 | Verb | n.s. | n.s. | 7.8 (-0.28~) | n.s. |
| | T6 | Verb | n.s. | n.s. | n.s. | n.s. |
| | P3 | Verb | n.s. | n.s. | n.s. | n.s. |
| | P4 | Verb | n.s. | n.s. | n.s. | n.s. |
| | O1 | Verb | n.s. | n.s. | n.s. | n.s. |
| | O2 | Verb | n.s. | n.s. | n.s. | n.s. |

*** -- $p<0.001$; ** -- $p<0.01$; * -- $p<0.05$; ~ -- $p<0.06$; n.s. -- non-significant

#### *7.3.2.5. Object (Noun) and VDN naming*

#### 7.3.2.5.1. Regression Analysis for Each Hemisphere

Multiple regression analysis showed that for object naming with RVF presentation, frequency of the produced nouns made its significant contribution to gamma areas of both hemispheres (LH: %Vars = 4.0; partial correlation *r* = -0.27; p<0.05; RH: %Vars = 4.5; partial correlation *r* = -0.28; p<0.05). For VDN naming in RVF presentation, imageability made unique contribution to the gamma variance in the LH (%Vars = 10.1; partial correlation *r* = 0.32; p<0.05). LVF presentation did not produced any significant result.

#### 7.3.2.5.2.2. Regression Analysis for Each Channel

Multiple regression analysis of object naming task revealed only single significant contribution to the gamma variance: frequency influenced gamma oscillations in P4 (%Vars = 5.9; partial correlation *r* = -0.25; p<0.05) when pictures were presented to the RVF.

Results of stepwise multiple regression for VDN naming task are shown in Table 14. In LVF presentation only concreteness contributed to gamma area in F8. No other significant contribution to gamma area in LVF picture presentation condition was found. In RVF Imageability activated gamma oscillations in F8, C3, T5, P3 and O1.

Thus, regression analysis revealed frequency contribution to gamma elicited by both hemispheres in object naming task in RVF condition. Separate analysis showed that only right parietal was responsible for frequency contribution to the RH. LH frequency contribution was, probably, weakly distributed over channels and did not appeared in the separate analysis. Regression analysis of predictors in VDN action naming task revealed strong individual contribution of imageability mainly to LH channels in RVF presentation condition. In LVF only concreteness made unique contribution to gamma variance in right frontal area.

Table 14: Unique contributions to gamma area of each predictor when entered on the last step and partial correlations, separately for each VF and each channel for VDN picture naming task

| VF | Channel | Length, %Vars ($r$=) | Frequency, %Vars ($r$=) | Imageability, %Vars ($r$=) | Concreteness, %Vars ($r$=) |
|---|---|---|---|---|---|
| R | F7 | n.s. | n.s. | n.s. | n.s. |
| | F8 | n.s. | n.s. | 8.8 (0.30*) | n.s. |
| | C3 | n.s. | n.s. | 8.7 (0.30*) | n.s. |
| | C4 | n.s. | n.s. | n.s. | n.s. |
| | T5 | n.s. | n.s. | 9.2 (0.31*) | n.s. |
| | T6 | n.s. | n.s. | n.s. | n.s. |
| | P3 | n.s. | n.s. | 8.5 (0.30*) | n.s. |
| | P4 | n.s. | n.s. | n.s. | n.s. |
| | O1 | n.s. | n.s. | 9.7 (0.32*) | n.s. |
| | O2 | n.s. | n.s. | n.s. | n.s. |
| L | F7 | n.s. | n.s. | n.s. | n.s. |
| | F8 | n.s. | n.s. | n.s. | 10.6 (-0.33*) |
| | C3 | n.s. | n.s. | n.s. | n.s. |
| | C4 | n.s. | n.s. | n.s. | n.s. |
| | T5 | n.s. | n.s. | n.s. | n.s. |
| | T6 | n.s. | n.s. | n.s. | n.s. |
| | P3 | n.s. | n.s. | n.s. | n.s. |
| | P4 | n.s. | n.s. | n.s. | n.s. |
| | O1 | n.s. | n.s. | n.s. | n.s. |
| | O2 | n.s. | n.s. | n.s. | n.s. |

* -- $p<0.05$; n.s. -- non-significant

#### 7.3.2.6. Conclusion

It seems from ANOVA results that action naming activated more LH, in particular, left frontal area. Interestingly, in SMA and temporal regions object naming showed higher gamma activation than action naming, and in parietal and occipital regions action naming showed higher activation than object naming simultaneously with the sensitivity to imageability levels depending on VF. Taking into account the overall action naming difficulty in comparison to object naming, it could be suggested that left occipital and right parietal regions showed processing difficulty pattern concerning mainly visual and conceptual processing of action pictures. In contrast, SMA and temporal regions, probably, reflected activation pattern concerning object processing.

Temporal, SMA and parietal areas appeared to be sensitive to VF and imageability of the response words, that is, these regions were actively involved in concept activation and picture processing. SMA area was not much activated in action naming task which may mean that high perceptual and cognitive demands on the task might suppress motor associations. In addition, as it was mentioned before, no pre-test for visual/motor associations was done and not all the stimuli represented active movement. The results are in agreement with other studies (Murtha et al., 1999; Damasio et al., 1996) that suggest that temporal lobes may be involved not only in lexical retrieval but also in visual/perceptual processing, that is, in some semantic activation. Right parietal lobe appeared to be actively involved in picture processing, in particular, in action picture, which is in agreement of results by Levelt et al. (1998). That is, as Levelt et al. (1998) showed, P4 was involved not only/just in lemma selection but also in visual attention. Recall that action pictures were more complex than object pictures. It may be suggested that visual attention was reflected in the overall load on the short-term memory. VDN and object naming showed an activation pattern throughout the electrode sites. All areas were sensitive to imageability of response words and more active when the imageability of responses was high. Thus, both hemispheres were involved in conceptual processing in this subject independent on VF. Moreover, RH showed to be more activated processing highly imageable objects in parietal and occipital areas.

Regression analysis of object/action naming data showed that LVF (RH) object presentation activated response word length and frequency in the right occipital lobe which suggest that right occipital area was involved not only in visual/conceptual processing but also in lemma and lexeme selection. Response verb imageability activated left temporal area and response noun imageability activated right temporal area in LVF (RH) condition. RVF (LH) picture presentation showed contribution of various response word characteristics to the right hemispheric areas. Note that gamma response to the stimuli and tasks in similar to the gamma response in noun/verb (word) naming experiment. Thus, if accept 'facilitation' hypothesis that is, contribution of predictors to gamma area variance showed rather processing load than the ease of process then presentation of object and action pictures to the RVF (LH) facilitated the processing in the LH and put an additional load on the RH. Presentation of object and action pictures as well as presentation of nouns and verbs to the LVF (RH) facilitated processing in more anterior parts and put an additional load on more posterior parts of both hemispheres.

Regression analysis of object/VDN naming showed that presentation to the RVF (LH) activated mostly imageability of the VDN response words in all LH sites but frontal and in the right frontal area. Object presentation activated only frequency of the response words. LVF (RH) picture presentation activated only concreteness of VDN responses. Thus, the participants subjected to the noun/VDN and object/VDN naming experiments showed non-overlapping patterns of gamma activation in the two tasks. Recall, that in word naming experiment word presentation to the RVF (LH) activated only noun frequency in left occipital area, while word presentation to the LVF (RH) activated various word characteristics (both noun and VDN) in posterior parts of the brain, similarly to the activation of different word features in the same LVF (RH) condition of a participant, assessed to the noun/verb naming experiment.

Overall, the results showed trivial individual differences between the two subjects although the differences could also be attributed to the different experimental contexts. Both types of analysis showed that gamma oscillations differently reacted to various conditions, showing two types of strategy: activation and processing difficulty one. In addition, it was hypothesized that two types of analysis showed different sides of one processing: ANOVA was associated with gamma sensitivity to variables, and regression was associated with the processing load and involvement of various word features in the processing.

The results of picture and word naming suggested that areas involved in the processing were widely distributed and might subserve different functions that were dependent on both VF and on picture and response word characteristics.

# CHAPTER 8. CONCLUSION

The present study had several goals. One goal of the research was to explore visual field differences in word and picture processing using word naming and picture naming tasks. The interest was mainly on what word and picture characteristics and how would influence word and picture processing in terms of reaction times and how the processing depends on the field of presentation. The word characteristics were their grammatical class and lexical and semantic properties. As picture characteristics, consensus in naming a picture was considered. In addition, the same lexical and semantic properties of response word were also taken into account. Bulgarian, unlike English, has unambiguous form-class distinctions between nouns and verbs. This clear distinction between the two classes permitted to avoid confounding variable of grammatical class that frequently exists in psycholinguistic research. Of special interest of the study were verb-derived nouns. The interest lied in their ambiguity between their relatedness to grammatical class of nouns and action semantics that they bear. One of the predictions was that in word naming task verbs would be processed slower than nouns because of their greater conceptual complexity over nouns, and verb-derived nouns would behave closer to nouns than to verbs and/or generally would be processed slower/harder than nouns and verbs because of their ambiguous status. Analysis of variance showed that verbs were processed faster than nouns and verb-derived nouns, and verb-derived nouns were processed slower than the two other grammatical classes. Verb advantage in processing was attributed to the overall experimental context. On the other hand, regression analysis suggested that the same verbal properties were activated when the words were presented to the RVF that is, the processing of the three classes was not different in that sense. Word presentation to the LVF activated imageability characteristics of verbs and nouns and none of the characteristics was activated with verb-derived noun presentation to the LVF. The absence of contribution of any of VDN properties was explained by their considerably longer than that of nouns and verbs, length, and by their complexity expressed in the ambiguity between their grammatical status and semantic content. The results showed that presentation to different visual field prompted differential brain strategies (or patterns of processing) and that in the absence of VF x independent variable interaction it is still possible to explore VF differences. Thus, the results suggested the usefulness of other analysis in addition to ANOVA and the existence of different brain processing strategies that depended on word properties and field of presentation. The results supported the dual coding theory (Paivio, 1990; 1991).

Another goal of the study was to uncover factors that influence picture naming processing latencies in lateralized presentation mode and to address the issue of what information sources are commonly and differentially available in the two divergent presentation modalities and tasks (visual word and picture naming). ANOVA results showed that object naming was considerably easier task than action and verb-derived action naming. The reason may lie both in the differences in visual complexity of the pictures and in the differences in cognitive processing required to complete the task. Regression analysis revealed more divergent and vague strategies than showed word naming task. Object naming was influenced by frequency of the response words in both visuals fields while action naming activated length and imageability when pictures were presented to the RVF and concreteness with LVF presentation. VDN action naming activated only concreteness in RVF presentation mode. The only convergent result was consensus influence on RT in all types of picture naming and in both VF presentation modes. Thus, while there were some similarities between information activation sources in word naming and picture naming tasks (e.g., noun frequency and verb length activation in RVF condition), it was clear that for complex picture naming task not enough factors were taken into account in order to have an understanding of interrelation and behaviour of each factor in each condition. On the other hand, variations in information activation sources suggested that presentation to one or another visual field may activate different in their qualitative characteristics information sources in both hemispheres. That is, in terms of the dual coding theory, both logogen and imagen systems can be activated in both hemispheres dependent on different conditions. The results that imageability of the produced verbs was activated in RVF condition is in agreement with Richardson (1999) note that imageability effect is associated with bilateral activation even in patients with damage within either hemisphere. Thus, it seems to be the result of mechanisms within both hemispheres. It may be suggested that both verbal and nonverbal systems may have different within and between hemispheric weights that are highly dependent on intrinsic properties of words and concepts.

The last goal was to use gamma-band oscillations as a measure of processing and to study how gamma would reflect word properties and how it would react on different experimental conditions. The only expectation was gamma activation in occipital area and SMA in respond to nouns and verbs that was not fulfilled. However, examination of ANOVA and regression analysis results suggested that gamma oscillations showed not only activation in respond to conditions but also a processing difficulty strategy, analogous to RT. Moreover, it was hypothesised, that absence of predictor contribution to gamma may show routine, facilitative processing while presence of such a contribution may indicate processing load. This hypothesis could be tested in alpha-range. Alpha should show the following behaviour: with easy processing alpha would be more active than with a more complex and resource-demanding processing.

Two subjects showed a few similarities in processing of words and pictures in terms of activation areas (e.g., right parietal activation) and more differences. The overall pattern of the results showed overlapping areas involved in different types of processing dependent on experimental conditions which suggest that the same areas may execute different functions in respond to conditions.

Overall, it could be suggested that gamma oscillation as a measure may be more informative than RT. Although the analysis was based only on two subjects and it is premature to confidently claim the two-side processing reflection of gamma-band, it seems that gamma as a measure could become a promising area to study.

Regression analysis showed to be useful technique in addition to ANOVA that could reveal information activation patterns and sources uncovered by ANOVA in the two, RT and EEG/gamma experiments.

Finally, the results of especially picture naming experiments showed that more careful and detailed account should be taken to the stimuli characteristics to understand better the processing peculiarities. It seems that such important factors as age of acquisition, familiarity with an object, animacy, categories of an object and conceptual characteristics/the degree of motor associations of a verb, verb valence, morphological structure etc. have to be taken into account and, possibly, will shed some additional light on the overall processing.

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## APPENDIX 1

### WORD STIMULI USED IN WORD NAMING EXPERIMENTS

Verbs

| English | Bulg |
|---|---|
| DRINK | PIJA |
| BARK | LAJA |
| BEG | PROSJA |
| BRUSH | MIJA |
| BURN | GORJA |
| CALL | VIKAM |
| CARRY | NOSJA |
| CLAP | PLJASKAM |
| COOK | GOTVJA |
| COUNT | BROJA |
| CRASH | PADAM |
| CRAWL | LAZJA |
| CRY | PLACHA |
| DIG | KOPAJA |
| DIP | TOPJA |
| DRAW | PISHA |
| DRIP | KAPJA |
| DRIVE | KARAM |
| FISH | LOVJA |
| FLOW | TEKA |
| FLY | LETJA |
| FRIGHTEN | PLASHA |
| FRY | P^RZHA |
| HIT | UDRJAM |
| HOWL | VIJA |
| IRON | GLADJA |
| KICK | RITAM |
| KNIT | PLETA |
| LIE | LEZHA |
| LIGHT | PALJA |
| MAIL | PUSKAM |
| MEASURE | MERJA |
| MILK | DOJA |
| PECK | K^LVA |
| PEEL | BELJA |
| PET | GALJA |
| PLOW | ORA |
| PULL | D^RPAM |
| PUSH | BUTAM |
| RIDE | JAZDJA |
| ROW | GREBA |
| RUN | TICHAM |
| SAW | REZHA |

Nouns

| English | Bulg |
|---|---|
| barrel | b^chva |
| bear | mechka |
| bed | leglo |
| bee | pchela |
| book | kniga |
| box | kashon |
| butter | maslo |
| canoe | lodka |
| cat | kotka |
| chimney | komin |
| cloud | oblak |
| cork | tapa |
| desert | kaktus |
| desk | bjuro |
| dragon | drakon |
| dress | roklja |
| eagle | orel |
| ear | yho |
| egg2 | jajtse |
| feather | pero |
| fly | muha |
| gate | vrata |
| girl | momiche |
| gorilla | gorila |
| harp | arfa |
| hook | kuka |
| igloo | iglu |
| jacket | jake |
| jigsawpuzzle | p^zel |
| jumprope | v^zhe |
| knight | ritsar |
| knot | v^zel |
| lamp | lampa |
| llama | lama |
| monk | monah |
| moose | elen |
| mosquito | komar |
| mouse2 | mishka |
| owl | buhal |
| panda | panda |
| peacock | paun |
| pear | krusha |
| pirate | pirat |

VDN

| English | Bulg | VDN |
|---|---|---|
| DRINK | PIJA | ПИЕНЕ |
| BARK | LAJA | ЛАЕНЕ |
| BEG | PROSJA | ПРОСЕНЕ |
| BRUSH | MIJA | МИЕНЕ |
| BURN | GORJA | ГОРЕНЕ |
| CALL | VIKAM | ВИКАНЕ |
| CARRY | NOSJA | НОСЕНЕ |
| CLAP | PLJASKAM | ПЛЯСКАНЕ |
| COOK | GOTVJA | ГОТВЕНЕ |
| COUNT | BROJA | БРОЕНЕ |
| CRASH | PADAM | ПАДАНЕ |
| CRAWL | LAZJA | ЛАЗЕНЕ |
| CRY | PLACHA | ПЛАЧЕНЕ |
| DIG | KOPAJA | КОПАЕНЕ |
| DIP | TOPJA | ТОПЕНЕ |
| DRAW | PISHA | ПИСАНЕ |
| DRIP | KAPJA | КАПЕНЕ |
| DRIVE | KARAM | КАРАНЕ |
| FISH | LOVJA | ЛОВЕНЕ |
| FLOW | TEKA | ТЕЧЕНЕ |
| FLY | LETJA | ЛЕТЕНЕ |
| FRIGHTEN | PLASHA | ПЛАШЕНЕ |
| FRY | P^RZHA | ПЪРЖЕНЕ |
| HIT | UDRJAM | УДРЯНЕ |
| HOWL | VIJA | ВИЕНЕ |
| IRON | GLADJA | ГЛАДЕНЕ |
| KICK | RITAM | РИТАНЕ |
| KNIT | PLETA | ПЛЕТЕНЕ |
| LIE | LEZHA | ЛЕЖАНЕ |
| LIGHT | PALJA | ПАЛЕНЕ |
| MAIL | PUSKAM | ПУСКАНЕ |
| MEASURE | MERJA | МЕРЕНЕ |
| MILK | DOJA | ДОЕНЕ |
| PECK | K^LVA | КЪЛВАНЕ |
| PEEL | BELJA | БЕЛЕНЕ |
| PET | GALJA | ГАЛЕНЕ |
| PLOW | ORA | ОРАНЕ |
| PULL | D^RPAM | ДЪРПАНЕ |
| PUSH | BUTAM | БУТАНЕ |
| RIDE | JAZDJA | ЯЗДЕНЕ |
| ROW | GREBA | ГРЕБАНЕ |
| RUN | TICHAM | ТИЧАНЕ |
| SAW | REZHA | РЯЗАНЕ |

| | |
|---|---|
| SHARPEN | TOCHA |
| SING | PEJA |
| SMELL | MIRISHA |
| SMOKE | PUSHA |
| SNOW | VALJA |
| SPIN | PREDA |
| SPIT | PLJUJA |
| SPREAD | MAZHA |
| STEAL | KRADA |
| SWEEP | META |
| SWIM | PLUVAM |
| TEAR | K^SAM |
| TELEPHONE | GOVORJA |
| THINK | MISLJA |
| WATCH | GLEDAM |
| WAVE | MAHAM |
| WIPE | B^RSHA |

| | |
|---|---|
| pizza | pitsa |
| potato | kartof |
| seal | tjulen |
| ship | korab |
| shirt | riza |
| sink | mivka |
| skirt | pola |
| slingshot | prashka |
| spider2 | pajak |
| tail | opashka |
| tiger | tig^r |
| toaster | toster |
| top | pumpal |
| trashcan | kofa |
| trophy | kupa |
| vase | vaza |
| wing | krilo |

| | | |
|---|---|---|
| SHARPEN | TOCHA | ТОЧЕНЕ |
| SING | PEJA | ПЕЕНЕ |
| SMELL | MIRISHA | МИРИСАНЕ |
| SMOKE | PUSHA | ПУШЕНЕ |
| SNOW | VALJA | ВАЛЕНЕ |
| SPIN | PREDA | ПРЕДЕНЕ |
| SPIT | PLJUJA | ПЛЮЕНЕ |
| SPREAD | MAZHA | МАЗАНЕ |
| STEAL | KRADA | КРАДЕНЕ |
| SWEEP | META | МЕТЕНЕ |
| SWIM | PLUVAM | ПЛУВАНЕ |
| TEAR | K^SAM | КЪСАНЕ |
| TELEPHONE | GOVORJA | ГОВОРЕНЕ |
| THINK | MISLJA | МИСЛЕНЕ |
| WATCH | GLEDAM | ГЛЕДАНЕ |
| WAVE | MAHAM | МАХАНЕ |
| WIPE | B^RSHA | БЪРКАНЕ |

**APPENDIX 2**

PICTURE STIMULI USED IN WORD NAMING EXPERIMENTS

Object naming

| English | Bulgarian |
|---|---|
| ALLIGATOR | krokodil |
| ANCHOR | kotva |
| APPLE | jab^lka |
| AQUARIUM | akvarium |
| ARM | r^ka |
| ARROW | strela |
| BALL | topka |
| BALLOON | balon |
| BANANA | banan |
| BAT | prilep |
| BED | leglo |
| BELT | kolan |
| BENCH | pejka |
| BICYCLE | kolelo |
| BINOCULARS | binok^l |
| BONE | kok^l |
| BOOK | kniga |
| BOOT | botush |
| BREAD | hljab |
| BROOM | metla |
| BUTTERFLY | peperuda |
| BUTTON | kopche |
| CAMEL | kamila |
| CANDLE | svesht |
| CANE | bastun |
| CAR | kola |
| CARROT | morkov |
| CAT | kotka |
| CHAIR | stol |
| CIGARETTE | cigara |
| COMB | greben |
| COW | krava |
| cross | kr^st |
| DEER | elen |
| DESK | bjuro |
| DOG | kuche |
| DOLPHIN | delfin |
| DOOR | vrata |
| DRUM | baraban |
| EAR | yho |
| EGG | jajtse |

Action Naming

| Englidh | Bulg |
|---|---|
| DRINK | PIJA |
| PAINT | RISUVAM |
| CUT | REZHA |
| BLOW | DUHAM |
| ATTACK | LETJA |
| BOIL | GOTVJA |
| BOWL | HV^RLJAM |
| BRUSH | MIJA |
| CALL | VIKAM |
| CARRY | NOSJA |
| CLOSE | OTVARJAM |
| CRAWL | LAZJA |
| CRY | PLACHA |
| CURTSEY | tantsuvam |
| DELIVER | otvarjam |
| DRAG | NOSJA |
| DRILL | streljam |
| DUST | meta |
| EAT | JAM |
| FEED | HRANJA |
| FLY | LETJA |
| FOLD | SG^VAM |
| FRY | gotvja |
| GRILL | GOTVJA |
| HANG | PROSTIRAM |
| HOWL | laja |
| HUG | PREGR^SHTAM |
| IRON | GLADJA |
| JUGGLE | ZHONGLIRAM |
| KICK | RITAM |
| KNEEL | KOLENICHA |
| LIE | LEZHA |
| LISTEN | SLUSHAM |
| LOCK | OTKLJUCHVAM |
| MAIL | PUSKAM |
| PLUG | VKLJUCHVAM |
| PUSH | BUTAM |
| RAIN | VALJA |
| READ | sedja |
| RIDE | JAZDJA |
| RUN | TICHAM |

VDN action naming

| English | BulgVerb |
|---|---|
| DRINK | PIJA |
| PAINT | RISUVAM |
| CUT | REZHA |
| ATTACK | LETJA |
| BOIL | GOTVJA |
| BOWL | HV^RLJAM |
| BRUSH | MIJA |
| CARRY | NOSJA |
| CRAWL | LAZJA |
| CRY | PLACHA |
| CURTSEY | tantsuvane |
| DRIP | KAPJA |
| EAT | JAM |
| FEED | HRANJA |
| FLY | LETJA |
| FOLD | SG^VAM |
| FRY | gotvene |
| GOSSIP | GOVORJA |
| GRILL | GOTVJA |
| HANG | PROSTIRAM |
| HOWL | laene |
| HUG | PREGR^SHTAM |
| IRON | GLADJA |
| JUGGLE | ZHONGLIRAM |
| KICK | RITAM |
| KNEEL | KOLENICHA |
| LIE | LEZHA |
| LISTEN | SLUSHAM |
| LOCK | OTKLJUCHVAM |
| LOOK | OGLEZHDAMSE |
| MAIL | PUSKAM |
| MARCH | hodene |
| MASSAGE | MASAZHIRAM |
| PLUG | VKLJUCHVAM |
| POINT | POKAZVAM |
| POUR | SIPVAM |
| PULL | D^RPAM |
| PUSH | BUTAM |
| RAIN | VALJA |
| RIDE | JAZDJA |
| ROW | GREBA |

| | |
|---|---|
| ELEPHANT | slon |
| EYE | oko |
| FEATHER | pero |
| FENCE | ograda |
| FINGER | pr^st |
| FIRE | og^n |
| FISH | riba |
| FLOWER | tsvete |
| FLY | muha |
| FORK | vilitsa |
| FOX | lisitsa |
| GIRAFFE | zhiraf |
| GLASS | chasha |
| GLOBE | globus |
| GRAPES | grozde |
| GUITAR | kitara |
| GUN | pistolet |
| HAMMER | chuk |
| HORSE | kon |
| IRON | jutija |
| KANGAROO | kenguro |
| KEY | kljuch |
| KITE | hv^rchilo |
| LADDER | st^lba |
| LEAF | listo |
| LEG | krak |
| LEMON | limon |
| LIGHTBULB | krushka |
| LION | l^v |
| LIPSTICK | chervilo |
| LOCK | katinar |
| MONKEY | majmuna |
| MOON | luna |
| MOTORCYCLE | motor |
| NAIL | piron |
| NEEDLE | igla |
| NOSE | nos |
| PAIL | kofa |
| PALMTREE | palma |
| PAN | tigan |
| PAPERCLIP | klamer |
| PARROT | papagal |
| PEAR | krusha |
| PENCIL | moliv |
| PENGUIN | pingvin |
| PIG | prase |
| PIPE | lula |
| PLIERS | kleshti |
| POT | tendzhera |
| PYRAMID | piramida |
| RABBIT | zaek |

| | |
|---|---|
| SAIL | PLUVAM |
| SALUTE | KOZIRUVAM |
| SHOOT | STRELJAM |
| SIT | SEDJA |
| SLEEP | SPJA |
| SLICE | REZHA |
| SMOKE | PUSHA |
| SOW | hodja |
| SPREAD | rezha |
| SURVEY | GLEDAM |
| SWEEP | META |
| SWIM | PLUVAM |
| TEACH | POKAZVAM |
| THINK | MISLJA |
| THROW | HV^RLJAM |
| WAIT | sedja |
| WALK | HODJA |
| WATCH | GLEDAM |
| WIPE | gledam |

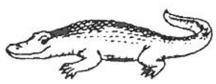
| | |
|---|---|
| RUN | TICHAM |
| SAIL | PLUVAM |
| SALUTE | KOZIRUVAM |
| SHOOT | STRELJAM |
| SIT | SEDJA |
| SLEEP | SPJA |
| SLICE | REZHA |
| SMILE | USMIHVAMSE |
| SMOKE | PUSHA |
| SPREAD | rjazane |
| STACK | REDJA |
| SUNBATH | PEKASE |
| SURVEY | GLEDAM |
| SWEEP | META |
| SWIM | PLUVAM |
| SWING | LJULEJASE |
| TEACH | POKAZVAM |
| THINK | MISLJA |
| WAIT | sedene |
| WALK | HODJA |
| WATCH | GLEDAM |

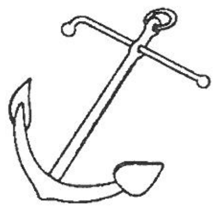
| | |
|---|---|
| RIFLE | pushka |
| RING | pr^sten |
| ROCKETSHIP | raketa |
| ROLLINGPIN | tochilka |
| ROOSTER | petel |
| SAW | trion |
| SCARF | shal |
| SCISSORS | nozhitsa |
| SCREWDRIVER | otverka |
| SHIP | korab |
| SHOE | obuvka |
| SHOULDER | ramo |
| SHOVEL | lopata |
| SKIRT | pola |
| SLINGSHOT | prashka |
| SNAIL | ohljuv |
| SOCK | chorap |
| SPOON | l^zhitsa |
| SUN | sl^ntse |
| SWAN | lebed |
| SWINGSET | ljulka |
| TABLE | masa |
| TENT | palatka |
| TOMATO | domat |
| TRAFFICLIGHT | svetofar |
| TREE | d^rvo |
| UMBRELLA | chad^r |
| VIOLIN | cigulka |
| WATCH | chasovnik |
| WATERINGCAN | lejka |
| WINDOW | prozorets |
| WINEGLASS | chasha |
| ZEBRA | zebra |

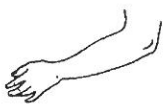
**APPENDIX 2 (CONTINUED)**

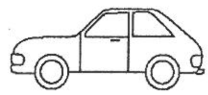
EXAMPLES OF PICTURE STIMULI

OBJECT NAMING





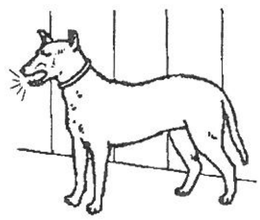




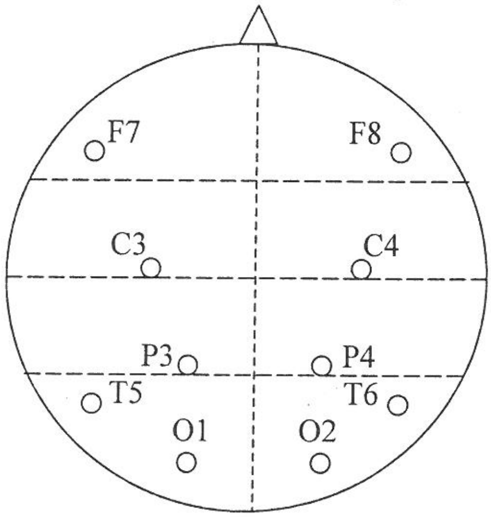
**APPENDIX 2 (CONTINUED)**

EXAMPLES OF PICTURE STIMULI

ACTION AND VDN ACTION NAMING

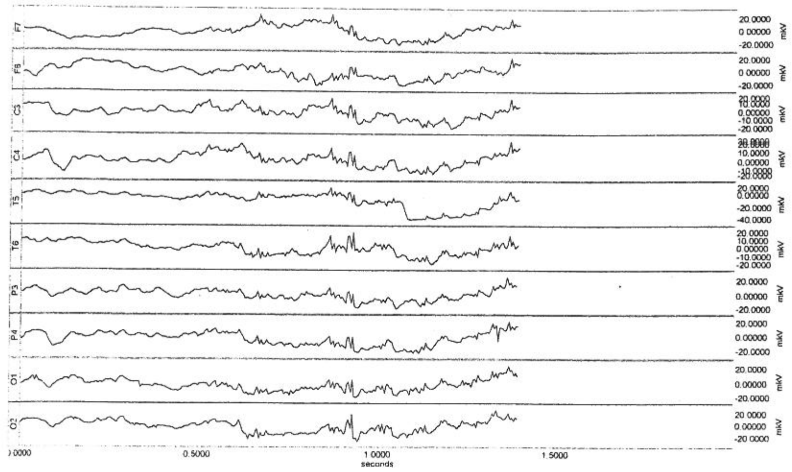


# APPENDIX 3

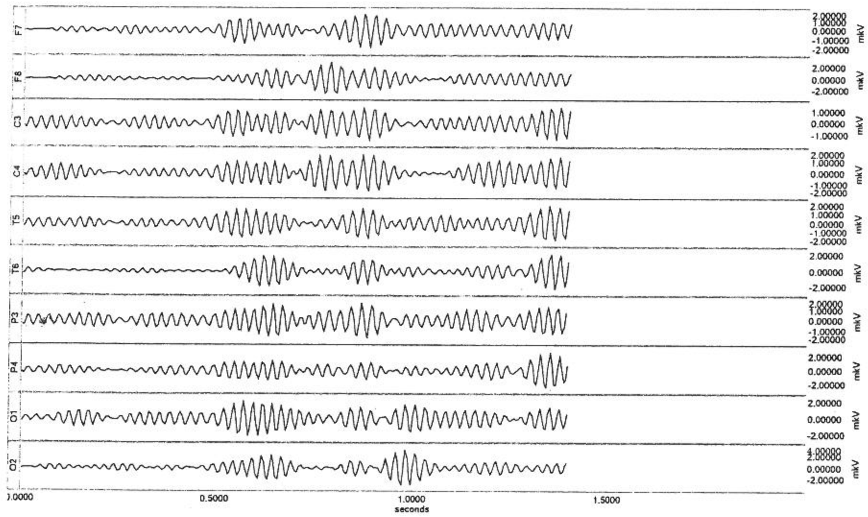



Schematic representation of electrode locations

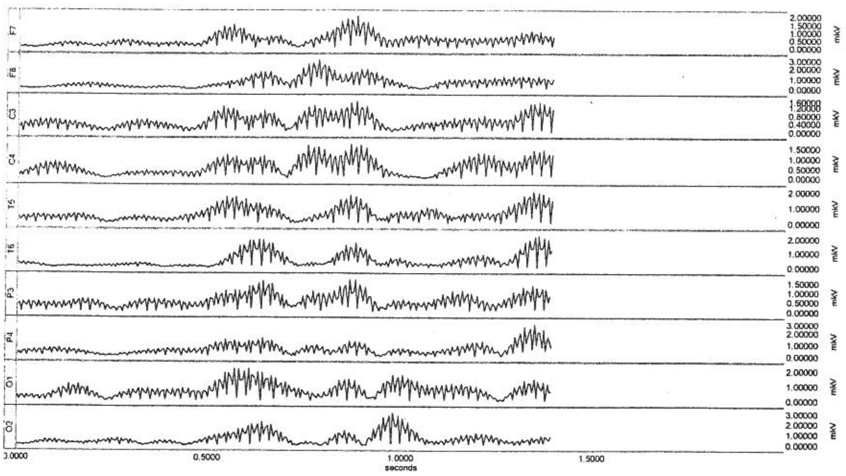
## APPENDIX 4



EGG data of a single stimulus (VDN picture)



Filtered gamma-band



Absolute value of gamma-band