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Electrophysiological Evidence for Sentence Comprehension: A Comparison of Adult, Normal Developing Children and Children with Specific Language Impairment

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1. INTRODUCTION

How people comprehend language is one of the central questions in psycholinguistics. Some facts are well established: the process of language comprehension is fast, at least in the most instances automatic and beyond the control of the listener. This constitutes an obvious obstacle for the research: while we can have direct access to the results of the process (correct answers to questions, for example), we have no direct insight into the process itself.

Linguistic account of language does not suffice for research into language comprehension. It can provide detailed descriptions of the abstract language systems and make claims about universal traits of human languages. However, in the mainstream of linguistic research the quest for the universal traits of all languages is closely associated with the work of Joseph Greenberg (Greenberg, 1963, Comrie, 1981) and, roughly, consists of comparing hundreds of world languages to find what is common between them. The alternative approach to the language universals emerged with the formulation of generative grammar (Chomsky, 1957, 1965) and with the idea that the universal traits of human languages are the ones that depend on our innate language structures or general architecture of human brain. Therefore, this approach in linguistics offers a linguistic account of the language comprehension and production, language learning and language acquisition. Although today an informed reader could easily see that Chomsky was plain wrong in questions of language innateness (for thorough account of 'innateness hypothesis' and related generativist claims see Sampson, 2002, 2005), his ideas, in fact, gave impetus to psycholinguistic research, in the first place into language acquisition.

Psycholinguistic research of language comprehension tries to relate the abstract linguistic knowledge to the language behavior of the speaker/listener. In this respect it can benefit from the outcome of the comprehension processes since it is measurable and liable to experimental manipulations. However, these manipulations allow only for indirect inferences about the comprehension processes and provide no direct insight into them.

Neuroscience approach to language comprehension looks for the biological substrate of language. The research is oriented towards finding the anatomical structures that carry out linguistic computations and identify the time course of the processes related to language comprehension.

The emerging interdisciplinary field of cognitive neuroscience encompasses the field of cognitive and experimental psychology, functional neuroimaging and cognitive science. When researching language the main goal is to link the cognitive architecture (represented in the language processing models) with the neural architecture (obtained in the neuroimaging or electrophysiological studies) and with the computational architecture or computational models that use artificial neural networks for modeling some aspect of linguistic behavior. This constitutes the triangle of cognitive neuroscience of language. The research can be focused on one of its angles or on one of its sides (i.e. on the link between the neural architecture and computational models, for example).

1.1. Sentence comprehension

There is little agreement about what sentence comprehension is. Philosophically speaking, sentence meaning is not necessarily very different from word meaning. Namely, in Western philosophical tradition that differentiates between meaning and sense (Frege, 1892), the meaning of the sentence is, in fact, its truth or falsehood; sentences are, in a sense, names for truth or falsehood in the same way words are names for objects. Their sense is described as what is common in two sentences in two different languages in order to be correct translations each of the other (Church, 1956). But how can a listener get to the sentence meaning; how comprehension is achieved? Psychologically speaking, this process is fundamentally different from word recognition or lexical knowledge. Sentence comprehension involves recognition of specific linguistic signal, its perception against background sounds due to the structured nature of the speech signal (noise is not structured). It also includes some specific linguistic processing (on different linguistic levels: phonological, lexical, morphosyntactic) and matching with one's encyclopedic knowledge and the context (see Figure 1). The specific linguistic computations are independent of the input modality (auditory or visual), i.e. they are domain-specific. However, the process of sentence comprehension is influenced by current context or listener's knowledge. Sentences rarely occur in isolation and their comprehension often depends on their integration into discourse.

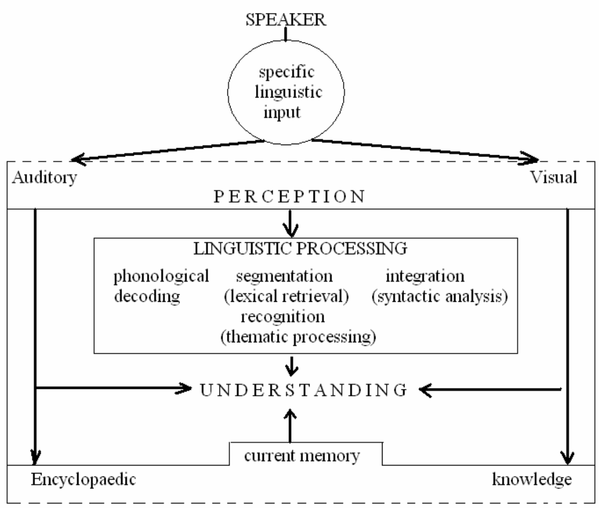

Figure 1. The process of sentence comprehension (based on Garman, 1990 and Cutler & Clifton, 1999)

The elements of the comprehension process – auditory and visual perception, linguistic processing (phonological, lexical, morphosyntactic), memory, knowledge – are not disputable. However, how they contribute to sentence comprehension is still left to various explanations.

There are two general approaches to the explanation of the notion of sentence comprehension. In the narrow sense it is simply a reconstruction of the meaning of the sentence from its parts in the processes that are called *parsing* and *interpretation*. Research in the area of parsing is approached mainly from the computational linguistics. It is defined as an analysis of the continuous stream of input in order to determine its grammatical structure. In computer science parser is a program that carries out this task. The output of the parsing procedure is some sort of data structure that has a hierarchical organization represented usually as a tree or with appropriate bracketing (in difference with the input, which is a stream of data). Interpretation is a procedure that links the syntactic structure obtained by the parsing procedure with semantics by applying some sort of thematic relations assignment procedure. Parsers are usually based on a particular linguistic theory, very often on Head Driven Phrase Structure Grammar (Pollard & Sag, 1994) due to the incorporation and making use of notions taken from computer science (e.g. 'knowledge representation', a notion that is needed for processing and classification of data in an information system; it is important for determining which aspect of data should be taken into account; for example, in a series 31, 28, 31, 30, 31 one *knows* what these data represent only if one knows that these are the numbers of days in the first five months in a year). Parsers do not entirely rely only on grammatical information and are usually in some aspect statistical – for example, they employ big corpora for training - or probabilistic rules to determine what aspect of meaning should be taken from the lexicon.

In the broader sense language comprehension includes building a reconstruction of the state of affairs described in the sentence (or sentences) where linguistic message is viewed as a set of instructions to achieve this goal. Sometimes in the latter sense a term *sentence understanding* is used (Garman, 1990) and it includes not only understanding of the individual parts of the linguistic message, but

> '…takes account of general knowledge about the events and incorporates elements that were not actually specified in the linguistic message (Garman, 1990: 305).

This account of sentence comprehension leads to the mental models or situation models of sentence comprehension (Johnson-Laird, 1983, 1989, van Dijk & Kintsch, 1983, Zwaan & Radvansky, 1998). This approach is psychologically more realistic and could therefore be promising in the studies employing the method of event-related potentials (ERP's), especially when ERP is used for studies that aim processes beyond the sentence level as in St. George et al. (1994) Van Berkum, et al. (1999), van Berkum (2004).

One of the general problems with studying sentence comprehension is the involvement of various factors of linguistic as well as non-linguistic in nature, so that it is not fully clear how these processes contribute to the changes detected. Linguistically, comprehension consists of a mapping from syntax to semantics. But how exactly is the meaning of the sentence built? On the level of individual words it can be said that words map into concepts. In the same way sentences map into sentence meanings. Words are combined into sentences via syntactic rules, but – to finish the drawing of this imagined rectangle – what is the nature of the process which combines concepts into sentence meanings? The idea that the sentence meaning is built up from concepts via specific recursive computations was proposed in the sixties (Katz & Fodor, 1963). It relies upon the fact that words and sentences, as well as their 'semantic' counterparts, concepts and sentence meanings are two different classes of objects with very different features. In a similar vein in a book that has been very influential in that time Fodor (1983) suggests that sentence comprehension is a 'bottom-up' process in which the computation is carried out in a encapsulated 'language module' which is not influenced by other cognitive abilities. The book triggered a controversy that is not resolved today: a big fault divides the tectonic plates of 'bottom-up' or 'modular' and 'top-down' models with interactive models of language comprehension in between. Fodor's philosophical analysis neglects the real-world situation: sentence comprehension is a process that unwinds in time and in this process many other factors play role; listener's expectations and knowledge, context, for example, or memory and attention. The role of working memory in sentence comprehension is especially emphasized due to the fact that the listener has to hold previous information while the new is rapidly hitting his input systems (Caplan, Waters, 1999). The model of working memory proposed by Baddeley and Hitch (Baddeley & Hitch, 1974, Baddeley, 1986, 1995, Gathercole & Baddeley, 1993) with its 'phonological loop' that keeps the information on-line provides a model that explains how this process works. A different approach to the problem of keeping the information in time (which is recognized as crucial in language comprehension) was taken in Pulvermüller (2002). The question that he raised was what kind of neural circuits could hold information active in the expectancy of the new information and the reverberating neural networks that can serve as some sort of information processing buffers were the solution.

The only way to explore this flow of information involved in the comprehension process empirically is obtaining some on-line evidence about what happens between the presentation of a stimulus and the achievement of understanding in an experiment.

1.1.1. On-line Methods for Sentence Comprehension Research

There are five major on-line methods (or groups of methods) employed in the research of sentence comprehension. They are: reaction time, reading time, eye-tracking, event-related potentials measurements (i.e. electrophysiological methods) and functional neuroimaging in the narrow sense (basically, functional magnetic resonance imaging, fMRI). In comparisons to various language tests these methods are much more suitable for capturing two important features of language: its speed and automatic processing. In addition, electrophysiological methods, as well as fMRI provide information about brain activity – its time course and localization, respectively.

Reaction time. It is a widely used method in experimental psychology developed by the Dutch physiologist F.C. Donders in the 19th century (Donders, 1868). He distinguished between three types of reaction times: *simple*, *recognition* and *choice* reaction times and showed that simple RT is shorter than recognition RT and that recognition RT is shorter than choice RT. This became known as the *subtraction method*. The reasoning was simple: if mental processes take time due to their dependency upon the nerve impulses that last for a measurable amount of time, then various mental processes require different amount of time depending on their complexity. If a condition X consists of a process A that takes t_1 time and if a condition Y consists of the process A and a process B and they both last for t_2 (and $t_2>t_1$), then process B takes t_2-t_1 time. This simple logic is today widely used in fMRI experiments (Raichle, 2001) subtracting images, not times. In exploring sentence comprehension reaction time measurements were mainly used in experiments designed to corroborate one of the sentence comprehension models (see next chapter). In the studies that employ other methods, for example, event-related potentials, reaction time is still used as a behavioral measure.

Reading time. Reading time is a similar measure; it usually takes the same kind of equipment to measure it (a board with a button and a computer program). The experiments using it usually employ a 'button-pressing paradigm' or 'self-paced reading' (Aaronson, Scarborough, 1976, Mitchell, Green, 1978, for review of the paradigms see Just et al. 1982 and Mitchell, 2004). Subjects are presented with sentences or a text word by word. They have to press the button to see the next word and they do it on their own pace. There are several paradigms: a sentence or a text can be presented in a cumulative way with the read word remaining on a screen, or in a non-cumulative way, a new word replacing the old one. The time that is required for the completion of reading is calculated between conditions that manipulate some aspect of sentence meaning. For example, O'Brian et al. (1988) wanted to see when readers made anaphoric inferences, i.e. when they drew inferences about what was not explicitly said in the presented text (e.g. if the word 'weapon' in a paragraph about robbing a lady occurred in the first sentence, when did the reader infer that it was, in fact, a knife? They showed that it happened immediately).

Although cheap and easy to implement, reading time has two drawbacks: first, that it generally slows down subject's reading by the 'artificial' requirement of button-pushing;

and second, that (in some versions) it is subject to various strategies of the participants (e.g. a participant in an experiment could press the buttons quickly and than read all the words of a sentence in peace).

In Croatia a version of reading time measure was widely used in elementary schools in the sixties and seventies to test children's ability to read. The quantity of the text read per minute was measured (Furlan, 1973) to detect children with reading problems. However, the reading time measure was not in the sense described above, i.e. to test the difference between experimental conditions.

Eye-tracking. Eye-tracking is immune to the above criticism in sentence comprehension studies. The technique employs a camera that is focused on an eye and records its motions. The reconstruction of the eye movement is based on the system's ability to reconstruct the centre of the pupil. The eye-tracking method makes use of the fact that the eye 'moves' in saccades, i.e. in brief movements from one to another point of fixation. Only during the fixation periods the information from the eye is available. Recording these points of fixation reveals what information is processed, in what order and for how long. In sentence comprehension studies that use this technique two assumptions are made (Pickering et al., 2004): immediacy assumption; that the information is processed as soon as it is encountered; and eye-mind assumption; that it is the word that is looked at that is processed.

The major advantage of eye-tracking method over reaction time or reading time measurements is the possibility to collect multidimensional data. While reaction time and reading time allows for one or two dependent variables (reaction time and, sometimes error rate), eye-tracking provides multidimensional data: the duration of the first fixation, the time spent in a region of fixation, regression (i.e. the leftward eye-movements) and the sum of all fixations (for review see Boland, 2004). In addition, it can be used beyond reading: a participant can hear the sentences while looking at the referents of their nouns. For example, in Kamide et al. (2003) anticipatory eye-movements were observed while subjects were listening to the sentences in which the verb 'subcategorize for the post-verbal arguments' (p.136) as in the two sentences:

(1) The woman will spread the butter on the bread.

(2) The woman will slide the butter to the man.

Presented with the pictures of bread and a man, the eye will fixate to bread in (1) and man in (2) as soon as the participant hears the word 'butter', i.e. in advance. This result was replicated in German (Knoeferle et al., 2005) in more complicated experiment that included structural ambiguity and intonation variations. Similar anticipatory eye movements were recorded in experiments that manipulated syntactic dependencies (e.g. filler-gap relations in Wh-questions as in Sussman & Sedivy, 2003). These results speak strongly against the mentioned bottom-up approaches to sentence comprehension.

Event-related potentials (ERP). Event-related potential is a 'set of voltage changes contained within an epoch of EEG [electroencephalogram] that is time locked to some event' (Coles & Rugg, 1995: 5). ERP is obtained when the random brain activity is filtered out in averaging process. Therefore, multiple presentations of the same stimulus (or the same category of stimuli) have to be presented to the participant. With multiple presentations of the same stimuli (multiple trials) the contribution of the background EEG subsides and favorable signal-to-noise ratio is achieved.

Just like eye-tracking, ERP provides multidimensional data: it provides data on latency of a process, scalp distribution and spectrum. It can also provide data on the neural generators of the brain activity, although it is not the best choice for that. With the millisecond resolution it can be used to find out *when* a process is going on in the brain. However, it can give limited information *where* it takes place (Hopfinger et al., 2005). The distribution of current recorded on the scalp can be consistent with infinitely many reconstructions of the neural generators (the problem known as the 'inverse problem' which is mathematically ill-posed) so the reconstructed sources of the activity as recorded on the scalp are in fact models. Nevertheless, different scalp distribution across experimental conditions tells us that the neuronal generators are different. ERPs reflect processing of sensory characteristics of the stimuli as well as cognitive processes elicited by the stimuli. ERP components sensitive to the physical characteristics of the stimuli (e.g. loudness or brightness) are referred to as the exogenous or obligatory components. On the other hand, the endogenous (or cognitive) components of the ERP are thought to be influenced by internal events, i.e. by the type of cognitive processing of the stimuli.

The waveform obtained in the averaging process is usually divided in ERP components. Generally, components are just positive or negative deflections that can be observed in an

ERP waveform. Components are conventions in ERP research. Their names usually consist of polarity and peak latency (N and P for negative and positive with a number attached to it; for example, N400 for a negative peak at approximately 400 milliseconds from the onset of the stimuli). Sometimes they have an ordinal number after the polarity sign. The ordinal number represents the position of the peak after the stimulus (e.g. P1 is the first positive wave after the stimulus, P2 second, etc.). Functional names are sometimes given; for example, Syntax Positive Shift (SPS) for a positive wave obtained with stimuli that contain syntactic error. Finally, sometimes the names are based on the scalp distribution, for example, 'left anterior negativity' (LAN) for the negative wave that can be recorded on the left frontal electrodes.

There is no complete agreement to what the components really mean (Coles & Rugg, 1995, Otten & Rugg, 2005). There are two general approaches to component identification: *physiological* and *psychological*. The first (*physiological*) approach is characterized by the claim that the neuronal population that carries out the activity that generates the recorded deflection in the ERP waveform should be specific (Näätänen & Picton, 1987). In other words, the defining characteristic of a component is its anatomical source (Coles & Rugg, 1995:8). The researchers who adopt the *psychological* approach claim that the component is, in fact, the information process that is manipulated in the experiment. The effect of this manipulation is visible as a deflection in the ERP waveform. So, components are the cognitive functions that are performed by brain (and are manipulated in experiments). In practice, the definition of the component comprises both physiological and psychological criteria (Otten & Rugg, 2005): while polarity and scalp distribution define the physiological characteristics, latency or sensitivity to certain stimuli define the psychological function that is manipulated in the experiment.

For some researchers in language comprehension ERP is close to the ideal research method (Osterhout et al., 1997). The ideal method should

> …provide continuous measurements during the process of interest, be differentially sensitive to events occurring at distinct levels of analysis and not rely on conscious judgments (ibid., p. 203).

With the temporal resolution of about 1 ms ERP provides real-time measure of brain activity. It records the summed activity of simultaneously occurring postsynaptic activity giving thus the direct information about the neuronal populations activated in the experiment. As noted above, it is a multidimensional measure; therefore, it is more likely to be sensitive to different aspects of the processes related to sentence comprehension. ERP proved to be particularly successful in sentence comprehension studies where the approach included the presentation of a linguistic anomaly. The first study that took this approach was the famous study by Kutas and Hillyard (1980) in which N400 was obtained in sentences in which the last word was semantically anomalous, i.e. did not fit into the sentence context. When syntactically anomalous sentences were presented, a different waveform was obtained, the P600 component or Syntactic Positive Shift (SPS) (Hagoort, et al., 1993, Osterhout & Holcomb, 1992, Hagoort et al. 2003). Some syntactic anomalies elicit different electrophysiological response: left anterior negativity (Friederici, 1995). Friederici (2002) also claim that word-category violation elicit even earlier syntactic component, early left anterior negativity or ELAN (for the criticism of her design see Hagoort, 2003).

In general, these results reveal the opposition between the two groups of responses: ones that are elicited by semantic and the ones that are elicited by syntactic violations. In a way, these results correspond to the analysis that views sentence comprehension as a two-foiled process in which, on one side, hierarchical structure is build and, on the other side, interpretation is given to the 'slots' that this structure prepares. However, at least some aspects of this view are wrong from the neurobiological point of view. From what is generally known about how neural circuits work, information processing in human brain is parallel and distributed. It can also be assumed that the same neurobiological principles work across different cognitive domains. Therefore, since we know that, for example, visual information is processed in dorsal and ventral streams that process *what* and *where*, respectively, similar design could be assumed for language processing, as well (i.e. one can assume similar syntactic and semantic 'streams'). By the same analogy, these 'streams' should be distinct, but highly interactive and a neurobiologically realistic model should take this into account. Therefore, what is computationally elegant (such as the syntax-first view on language comprehension), is not necessarily realistic in neurobiological sense. Indeed, recent research into various aspects of sentence comprehension reveal interaction between syntactic- and semantics related processes (e.g. manipulations of N400 and P600 amplitudes related to Agent animacy in active and passive sentences and verb transitivity as in Kuperberg et al., 2006; interaction between grammaticality and frequency in tense violations in irregular verbs that elicit earlier P600 response in high-frequency irregular verbs as in Allen et al, 2003; negative ‘slow wave’ between 550 and 1100 ms associated with mental image processing obtained in spatial sentences as in Noordzij et al., 2006; animacy (semantic) effects that interfere with sentence parsing and influence N400, P600 and LAN as in Weckerly and Kutas, 1999). Dorsal and ventral streams as a framework for understanding the relation between brain and language were proposed by Hickok and Poeppel (2004, 2007). They propose that the ventral stream carries out the mapping from sound to meaning, while the dorsal stream carries out mapping from sound to articulatory-based representations. However, no ERP data was offered to corroborate this idea (it was based on fMRI studies).

The opponents of this interactive view either search for syntax related components as early as 150 ms after the onset of the stimulus (‘early left anterior negativity’ or ELAN, Friederici et al., 1993) or claim that the syntactic processes have higher degree of automaticity (Gunter & Friederici, 1999).

Functional neuroimaging. In a narrow sense functional neuroimaging is restricted to hemodynamic functional brain imaging, functional magnetic resonance (fMRI), positron emition tomography (PET) and optical imaging in near infra-red spectrum (or optical topography). These methods register changes in the local cerebral blood flow thus providing indirect measure of brain activity. These methods do not have the millisecond time resolution, but their spatial resolution is much higher than the resolution of EEG (and there is no inverse problem). In addition, PET allows for the research into specific enzyme activity, receptors or transmitters due to the various radioactive tracers that are developed for it (for various research with PET see e.g. Senda et al., 2002).

Lower temporal resolution makes these methods less practical for the study of rapid processes involved in language comprehension. Therefore, different experimental paradigms are used in the fMRI studies. The most common paradigm is the blocked design (for overview of the paradigms see Donaldson & Buckner, 2002). The signal is acquired during one block of stimuli and is compared to the signal acquired in a different block that corresponds to a different task condition. If the equipment allows (rapid data acquisition, sensitivity of the equipment), event-related designs can be applied in fMRI experiments, as well.

The biggest advantage of hemodynamic methods is their excellent spatial resolution. The methods are therefore used for the localization of the processes involved in language comprehension (for overview see Bookheimer, 2002). However, sentence comprehension studies are rare due to the methods' limitations. In one such study Stromswold et al. (1996) used PET to show increased activation in left pars opercularis in left-branching sentences in comparison to 'easier' right-branching sentences claiming that this region has particular function in syntactic processing. In a more complicated paradigm that included both semantic and syntactic conditions Dapretto & Bookheimer (1999) have shown differences in activations: while activations in Brodmann's area (BA) 45 was increased in both conditions (Broca's area), they reported that BA 44 was strongly activated only in the syntactic condition and BA 47 (i.e. parts of the inferior frontal convolution) in semantic condition. Stronger activations in syntactic conditions were found in BA 22, 38, 39 and 40 as well (in the left temporal and parietal lobe, Wernike's area, superior temporal gyrus, angular and supramarginal gyrus). These differences corroborate dissociation between syntactic and semantic processing in language comprehension.

1.2. Modeling Sentence Comprehension

Model building has been the major conceptual tool for understanding the processes that take part in sentence comprehension. Models are, roughly, more elaborate hypotheses about these processes. In cognitive psychology they are a logical consequence of a view that cognitive processes can be understood as computations or information processing; therefore, language comprehension, production, reading or writing are usually represented as a flow chart.

There are two basic motivations for constructing sentence comprehension models; one originates from linguistics (or psycholinguistics) and the other from neurology. The first came along the formulation of generative grammar and the idea that linguistic theory should explain the linguistic knowledge of the speaker. Although Chomsky opposed the idea that language performance could tell us something about language competence, psycholinguistics profited a great deal from the opportunity to test the psychological implications of a linguistic theory. On the other hand, various types of aphasia motivated the formulation of the models that could explain how particular elements of language behavior could be impaired due to different positions of brain lesions (e.g. Wernicke-Geschwind model (Geschwind, 1972)). These two types of models operated with different notions: while *phonological encoding*, *noun phrase* or *thematic relations* are the building blocks of the former, *production, sound images* or *disconnections* were the notions typically encountered in the later models. Although today all models must provide a neurobiologically plausible picture of language-related processes, in this introduction the distinction between the psycholinguistic and neurolinguistic models will be kept in order to emphasize the information processing motivation of the former models and the interest in the brain substrate of the language function and its explanation in terms of other cognitive processes of the latter.

1.2.1. Psycholinguistic models

Serial processing and parallel processing models. Understanding sentences is fundamentally different from understanding words. While the process of word comprehension must involve some kind of checking the input against items stored in memory, the meaning of a sentence is constructed on line and the number of possible sentences is unlimited. Psycholinguistic models of sentence comprehension try to link the elements of grammar (phonology, morphology and syntax) to semantics; in other words sentence comprehension is viewed as some sort of mapping from form to meaning. Generally, there are two groups of psycholinguistic models: *serial processing* and *parallel processing models*, depending how they view the time-course of the processes. In serial processing models the parser builds the sentence structure in a step-by-step fashion, output of the previous being the input into the next step. The steps usually include several phases: from phonological decoding and word recognition to syntactic analysis, mapping onto semantics (thematic roles) and integration into wider discourse. The computation that is performed in each step (or phase) is encapsulated, automatic and fast. In parallel processing models all available information is processed when it is available. All available information is processed in parallel.

Until today there is no definite experimental evidence in favor or against any model and the discussion is still open. The psycholinguistic evidence that is sought to corroborate the processing models is usually based on ambiguous sentences and reaction time or reading time measurements. The main question dividing the processing model is how the parser proceeds with building the sentence structure when there is more than one possible reconstructed meaning of the sentence at some point in the sentence, as in:

(3) The evidence that the judge ignored the witness might have affected the jury.

(4) The evidence that the judge ignored might have affected the jury.

When the parser reaches the verb 'ignored', the sentence is ambiguous: in the first sentence the embedded clause is *that the judge ignored the witness*, while in the second sentence it is the *evidence* that the judge ignored, not the witness. In serial processing models it is assumed that the parser takes only one possible interpretation, goes on with it and if the rest of the incoming sentence proves to be inconsistent with it, requires repair or reinterpretation. In parallel models parser goes on with both possible interpretations and disposes the wrong one as soon as it reaches the point at which the ambiguity is resolved (Gibson, 1991, Gorrell, 1989, Hickok, 1993).

However, in parallel processing models some interpretations might be favorable; in other words, the parser does not treat all choices equally – if that is not assumed, these models would be falsified easily. There are two types of parallel processing models: *competition* and *non-competition*. The difference is in the influence of the preferred choice for sentence interpretation on the other possible choices. *Competition models* claim that there is such an influence that renders non-preferred choices less likely; i.e. that possible choices for sentence interpretation compete. In the *non-competition models* there is no such influence.

Serial models are further divided into *deterministic* (e.g. Frazier & Clifton, 1996, Frazier & Rainer, 1982) and *probabilistic* (Ferreira & Henderson, 1990, Jurafsky, 2002) depending on how the initial choice of the parsing procedure is selected. In *deterministic* models the parser always selects the same interpretation for an ambiguity in the sentence. For example, locality is an important constraint that guides the parsing procedure in deterministic models; it causes a preference for the interpretation with the local attachment over the interpretation with less local attachment. In the sentence

(5) *The bartender told the detective that the suspect left the country yesterday.*

(Example taken from Gibson & Pearlmutter, 1998)

the adverb *yesterday* is attached to the local clause *the suspect left the country* rather than the less local main verb *told.* In *probabilistic* models the parser will choose the most probable option. This explains why the parser takes the most preferable option as its choice for sentence interpretation in case of ambiguity. This also means that sometimes the less preferred options will be chosen instead.

Serial and parallel processing models make different predictions about ambiguities. If the parser computes only one interpretation and if somehow takes the correct one, than there would be no increase of reaction time or reading time in an experimental situation. If the reaction time or reading time increased in the same situation, this meant that the parser computed more than one interpretation of the sentence. Significant differences in reaction times or reading times between sentences (3) and (4) indicates repair or reinterpretation processes (although ranking mechanisms in parallel processing models account for such differences, as well, see for example, Boland, 1997).

Deep vs. shallow models. Processing models differ in the amount of syntactic information they claim is available for processing as the listener hears the sentence. Full sentence parsers provide a full syntactic tree as an output while shallow parsers provide only the major constituents of the sentence. For example given the sentence

(6) *The bank has powerful means and instruments for reaching its financial goals.*

a full sentence parser would give a complete tree-structure with all the dependencies on place. It would make clear whether the adjective *powerful* modifies the phrase *means and instruments* and not only *means* (i.e. whether the sentence structure includes [powerful [means and instruments]] or [[powerful means] and [instruments]]). Shallow parsers do not provide such an output. In the sentence (6) it would just group [powerful means and instruments] together.

In computational linguistics shallow parsers are viewed as an alternative to full-sentence parsing, an alternative with some practical advantages. Performing only partial syntactic analysis of the sentence can be useful in many large-scale language processing applications such as text summarization. When the concept of shallow parsing was conceived, learning methods were used to recognize patterns in sentences (Ramshaw & Marcus, 1995). The idea of pattern recognition is suitable for applications using neural networks and this makes it interesting for language comprehension modeling.

Apart from applications in computational linguistics, psycholinguistic evidence for shallow parsing is available, as well (Sanford & Sturt, 2002). The evidence includes underspecifications (Reyle, 1993) as in the following three sentences:

(7) Alice showed all her cameras to a technician.

(8) The technician worked in a big store.

(9) The technicians worked in a big store.

Given the two possibilities, that there is only one technician and that there are more of them, there should be a difference in reading times between the pairs <(7), (8)> and <(7), (9)> showing preference for one possible interpretation. However, no such difference is observed (Sanford & Sturt, 2002: 383) suggesting that a phrase *a technician* is underspecified in (7). Other psycholinguistic evidence include lack of error detection (and providing wrong answers) in sentences such as

(10) *How many of each animal species did Moses put on the Ark?*

(11) *Can a man marry his widow's sister?*

(12) *After an air-crash where should the survivors be buried?*

Bad scores in error detection (i.e. high rate of answering '2' to the question (10)) are explained as shallow processing of word meanings. Only a part of the word meaning is actually processed.

Finally, on the discourse level shallow processing is corroborated by the sentence interpretations that should be ruled out by grammar. Speakers understand as analog following two sentences (Sanford & Sturt, 2002: 384):

(13) *No head injury is too small to be ignored.*

(14) *No missile is too small to be banned.*

If we reformulate these sentences, the sentence (14) would be:

(14') *No matter how small it is, a missile should be banned.*

Reformulating (13) in an analogous way would give

(*13')* *No matter how small it is, a head injury should be ignored.*

This is, of course, not what listeners recognize as a meaning of the sentence (13); quite the opposite

(13") *No matter how small it is, a head injury should not be ignored.*

This is explained by the interference of world knowledge or context in the comprehension. The idea is that the parser's output is loose enough to allow these, strictly speaking, grammatically illicit interpretations. This interference of world knowledge (i.e. the sentence interpretation based on the knowledge and not on the grammatical structure itself) is called 'pragmatic normalization' (Fillenbaum, 1974). Similar experiments that involve participants' misinterpretation of garden-path sentences constructed with pragmatic or world knowledge interference such as

(15) While Anna dressed the baby spit up on the bed.

(where participants often incorrectly answer that Anna dressed the baby) can be found in Ferreira et al. (2001).

Psycholinguistic models are useful tools to identify elements to which language processes can be analyzed (although, of course, various models differ in the identification of particular elements of these processes). They do not specify brain circuits that carry on the computations, serially or in parallel. Nor do they say much about the contribution of other functions to the language function, in the first place memory. However, recently, new kind of psycholinguistic models emerge: they are based on artificial neural networks. These models constitute an independent field of research, usually in the field of computational linguistics. What ever the classification of this research be, models based on artificial neural networks allow for two other kinds of reasoning about language processes: first, reasoning about how particular elements can be learned and how they become organized in a particular way; and second, causal reasoning about “impaired” processes (e.g. Elman, 1991, Elman et al., 1996, Rumelhart & McClelland, 1986, Plunkett & Marchman, 1991.).

1.2.2. Neurolinguistic models

Neurolinguistic models identify the brain circuits that carry on linguistic computations and define time course of linguistic processes. They also try to define the role of other cognitive functions, for example memory or attention in the linguistic processes. They rely on brain imaging and lesion studies more than on behavioral data.

Declarative/procedural model. A model that accounts for all three issues mentioned in the previous paragraph is Declarative/procedural (DP) model proposed by Michael Ullman (Ullman, 2004). Obviously, the model views the organization of language in the brain as analogous to the organization of memory. The DP model claims that mental lexicon depends on the temporal-lobe substrates of declarative memory while mental grammar depends on a structure that includes frontal areas, basal ganglia, parietal and cerebellar areas that are involved in procedural memory. Ullman claims that a…

> …reasonable research program would thus be to identify domains that share commonalities with language: their underlying neural and computational systems will be promising candidates for those subserving language (Ullman, 2004:232).

The memory is the promising candidate. Since it is better understood than language, it is possible to make clear predictions about various aspects of language processing based only on non-language theories and data.

For example, if the brain system that underlies memory also underlies language, it can be predicted that the word knowledge would resemble the knowledge about facts: this knowledge will be acquired fast, probably based only on one exposure, while the grammatical knowledge, resembling procedural memory, requires years of learning and practicing. The DP model goes a step further: the same neural circuits that are involved in declarative and procedural memory are involved in lexical, i.e. grammatical processing:

> The brain structures that subserve declarative memory play analogous roles in lexical memory and … the brain system underlying procedural memory subserves the mental grammar (Ullman, 2004:245).

The structures that are involved in the grammatical/procedural memory system are basal ganglia (in particular caudate nucleus), frontal cortex (Broca's area and pre-motor regions) parietal cortex (supramarginal gyrus- BA 40) and possibly superior parietal lobule (BA 7), as well as superior temporal cortex, which is close related to the declarative memory system. In the grammatical/procedural system the cerebellum should also be included. Ullman includes medial temporal lobe into the lexical/declarative memory (encoding, consolidation), temporal and temporo-parietal areas (access and retrieval), as well as inferior and ventral temporal regions that are involving in non-linguistic conceptual knowledge. Superior temporal cortex plays a role in storing phonological representation. Both systems are strongly influenced by acetylcholine and estrogen (which also explains sex differences in language performance).

Ullman briefly discusses electrophysiological evidence in favor of his model. He quotes the ERP literature in which N400 was elicited in tasks that could be interpreted as lexical processing, but also in tasks that are related to non-linguistic conceptual-semantic processing. In the same way, LAN and P600 could be obtained in experiments that are related to automatic computations in general and not only with linguistic stimuli that reflect syntactic computations. An example of the non-linguistic procedural memory process that elicits LAN was an experiment in which incorrect positioning of tools was used as a stimulus (Bach *et al.*, 2002).

Ullman's DP model also accounts for data obtained from children with developmental language impairments, in particular with Specific Language Impairment (SLI) (about SLI as a procedural memory deficit, see Ullman & Pierpont, 2005). He claims that the deficit involves structures of procedural memory. Lexical knowledge is relatively spared in SLI, but lexical retrieval (word finding) is impaired in children with SLI. In addition, SLI is associated with impairments of procedural memory and motor deficits. Ullman claims that his model is corroborated by the evidence provided by research in developmental "non-language" disorders, such as dyslexia and Attention Deficit Hyperactivity Disorder (ADHD). Findings that cerebellum has been implicated in dyslexia, co-morbidity of dyslexia and SLI, as well as abnormalities in function of basal ganglia, especially *nucleus caudatus* in ADHD corroborate the claim that language supervenes on brain structures that are involved in other, primarily memory and motor functions.

Ullman claims that his model is not consistent with some connectionist models, '…in particular connectionist models that deny grammatical composition' (Ullman, 2004:249) since these models do not predict associations between grammatical domains and procedural memory, as well as their dissociation with lexical and declarative memory. His model is consistent with many dual-route models that make distinction between lexical knowledge and computational mental grammar that consists of several separable components. However, the models that he mentions in the article, mainly models that use key concepts of generative grammar, have at least one trait that is different from the DP model, the modularity. This also means that the Ullman's model is at least rather vague in questions such as primacy of syntax (as in 'syntax-first' models) or autonomy of syntax.

Neurocognitive model of sentence comprehension. Friederici's model (Friederici, 1995, 2002) is the most influential 'syntax-first' model today. It provides both spatial and temporal information about the processes that underlie language comprehension. The model is tested mainly in fMRI and ERP studies. It is a three-phase serial processing model; in the first phase the parser builds the sentence structure, in the second phase semantic information is linked to the structure in terms of thematic roles assignment and in the third phase repair and reinterpretation processes take place. The model recognizes the role of memory in language comprehension: memory structures closely related to language function (phonological memory, memory for syntactic structures) and 'general memory resources'. The three phases correspond to ERP components in the following order: first phase – ELAN, second phase – LAN, N400, and third phase – P600. The schematic overview of the model is given on Figure 2.

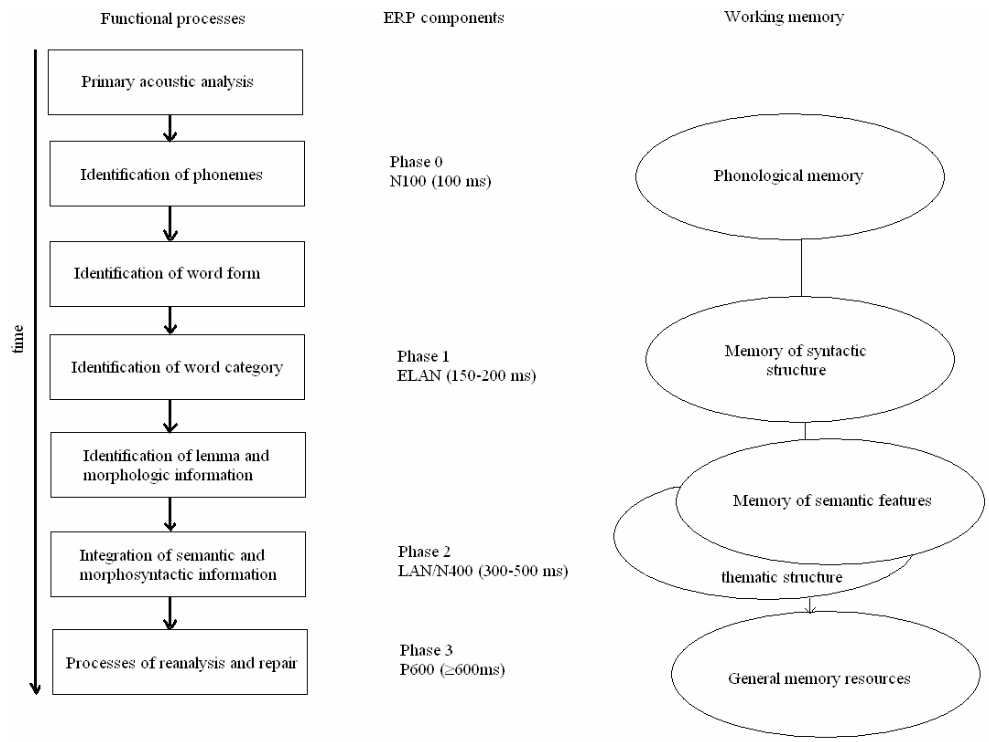

Figure 2. Friederici's model of sentence comprehension (based on Friederici, 2002)

In some details the model proposed in 2002 differs from the earlier version in which the claim 'syntax first' was stronger (Friederici, 1995). According to this earlier version two of the three phases are related to syntax: the first phase that corresponds to the first sweep of the parser, i.e. the initial building of the syntactic structure, and the third phase, that corresponds to the reanalysis and repair. The strong syntactocentric claim about the comprehension processes consists in the 'autonomy of syntax' view: no other processes contribute to the initial syntactic structure building and these processes precede other, semantic processes that occur in the second phase. In the third phase the parser maps the initial syntactic structure onto the available lexical/semantic information. In this phase an interaction between syntactic and semantic information might happen, but not before. In the 2002 model other non-linguistic processes are recognized too.

The ‘syntax-first’ model is obviously inspired by the generativist view on language with the ‘autonomy of syntax’ as the central idea. It needs some empirical evidence that can show the absence of early ‘integrative’ or non-syntactic processes. Friederici found this evidence in the absence of N400 component in experiments in which word-category violation was combined with semantic violation. In these experiments only ELAN was observed (Hahne & Friederici, 1998, Friederici, 1999).

The development of this model follows the developments in the generative theory. As the numerous imaging studies discover various brain areas involved in language processing, not only cortical, but also subcortical, and as the discussion on language evolution converge on the idea that the human language faculty developed as a lucky coincidence of various contributing factors that all evolved in various animal species, but not all of them in one species, the generativist idea of language as a ‘mental organ’ is (Chomsky, 1995, Anderson & Lightfoot, 2002) was replaced in the minimalist program with the idea that the only truly human linguistic trait is the hierarchical organization of language (that affects other cognitive abilities and not *vice versa*). The latest Friederici’s experiment (Friederici *et al.*, 2006) follows this line of thought attempting to show the difference between processing hierarchical and non-hierarchical sequences (transitional probabilities) in human brain, with the non-hierarchical processes being localized in the areas that are phylogenetically older than Broca’s area (left frontal operculum). The hierarchical processes were localized in the Broca’s area using fMRI. This dissociation explains why primates, that lack hierarchical organization of the learned symbolic communication, lack language. This reasoning is used as an argument against connectivist model in which probabilistic cues replace rule-based, hierarchical organization of language.

Memory Unification Control Model (MUC). Peter Hagoort (2003, 2005) proposed a neurolinguistic model that accounted for Friederici's results, but provided explanation for some other results that contradicted the syntax-first models. The crucial objection to the Friederici's model was the dependence of the ELAN on the order of the syntax-semantics violations, i.e. on the availability of the syntactic or semantic information in the timeline of the stimulus. In Friederici's experiment in which acoustic stimuli were used syntactic information is simply available before the semantic information as in examples (16) and (17):

(16) *Die Birne wurde im* gepflückt*. (The pear was being in-the* plucked*.)*

(17) *Die Freund wurde im besucht. (The friend was being in-the* visited*.)*

In these examples *im* (i.e. a preposition and the article *in dem*) requires a noun while prefixes *ge*- and *be*- require a verb, hence the word category violation and the ELAN. In Hagoort's Dutch examples this syntactic information is simply not available before the semantic information because the information about the word category is contained in the suffix, not in the preposition. The stimuli were acoustic, as well, and the target word lasted about 450 ms. It was after 300 ms that the word category information was available and this point was taken as a 'category violation point' or 'CVP'. The ELAN component was obtained at about 100 ms after the CVP, but N400 preceded it by approximately 10 ms because the semantic information was already available (Hagoort, 2003:23). This constitutes strong evidence against syntax-first models and in favor of immediacy models in which any information is processed as soon as it becomes available. Hagoort's model is based on the parsing model developed by Vosse and Kempen (2000). Their 'lexicalist grammar', as they call their model, simply means that the words in the mental lexicon are represented together with the syntactic frame. This means that the nouns are represented as heads of the NP phrases or prepositions as heads of PP phrases, as in Figure 3.

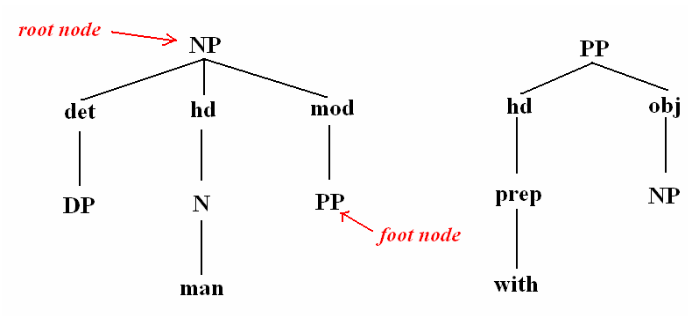

Figure 3. Representation of words in the mental lexicon

The unification process consists of lining up lexical frames with identical root and foot nodes. The phrase *the man with…* will be formed simply by attaching the DP-*det-the* entry (with the DP as the root node, (not on the Figure 3, but its structure is obvious)) to the DP foot node under the main NP node. The same operation will be applied for the PP with+NP. The PP root node will line up with the PP foot node under the main NP. If the sentence is ambiguous, as the sentence (18):

(18) The woman sees the man with the binoculars.

there will be competition between the foot nodes that can attach the PP *with the binoculars*. This competition (or 'competitional inhibition' in Vosse and Kempen, 2000) will eventually determine whether it is the woman who has the binoculars or the man.

In MUC Hagoort identifies the brain areas that carry out linguistic computations. As the language comprehension is a process that extends over time, the major requirement for the brain circuits that deal with language information is the ability to maintain information on-line. Finding the notion of Broca's area, traditional language area, 'ill-defined' and finding no reason 'to treat Broca's area as a natural kind' (Hagoort, 2005:419), Hagoort emphasizes the importance of the granular cortex that comprises of BA44 and BA47 that is involved in heteromodal processing. Unlike them, BA45 is a part of the Broca's area that is not granular. Hagoort concludes that it therefore makes sense to treat the left inferior frontal gyrus as the brain area in which the *unification* processes can take place (i.e. processes that do not depend on the input system, but are genuinely linguistic). It can hold on-line lexical information stored in the left temporal lobe and integrate them into representations of multi-word utterances. This lexical storage is the *memory* component in MUC. The role of the *control* component is a *liaison* to the communicative intentions or actions of the speaker (or listener). It accounts for the attentional control, turn taking or choice of a sociolect, for example. It is located in the anterior cingular cortex and the dorsolateral prefrontal cortex.

Combining psycholinguistic model of sentence comprehension developed by Vosse and Kempen with neuroimaging studies and trying to establish relations between the elements of the psycholinguistic model and the function of the identified brain areas has an obvious advantage over the 'syntax-first' models in which elements of psycholinguistic models are just mapped onto the data obtained in electrophysiological recordings or brain imaging. Memory in MUC corresponds to lexical storage and retrieval; unification in MUC corresponds to the integration of the lexical information into multi-word representation while control corresponds to the pragmatic information contained in the linguistic message. In other words, the model dissolves language comprehension process into brain functions that are not necessarily language specific in a rather natural way. The time course of these processes is not fixed – the information is processed as soon as it becomes available. This view is accordance with linguistic theories that take 'communication-and-cognition perspective' (e.g. Van Valin & LaPolla, 1997, Dik, 1978, Bresnan, 2001, Halliday, 2004) However, MUC does not depend on a particular linguistic (i.e. grammatical) theory in a way 'syntax-first' models follow the developments and revisions in generative tradition. It is very unconvincing for a neurocognitive model to undergo a revision whenever some linguist makes a change in a linguistic theory whether he bases the change on new linguistic evidence from a far away forest tribe or on elegance of the branching trees in his own syntactic forest on his computer.

1.3. Role and Reference Grammar as a Language Comprehension Research Tool

1.3.1. Basic concepts of Role and Reference Grammar (RRG).

It is claimed that the Role and Reference Grammar is a grammatical theory that can be taken as a language processing model, as well (Van Valin, & LaPolla, 1997, Van Valin, 2003). In this sense RRG has a methodological advantage over the rival theories that make no such claims: RRG can be empirically tested outside its primary area of interest, language typology. As a linguistic theory it operates with universally valid and not language specific notions. These two characteristics – RRG as a language processing model and RRG operating with universally valid notions that treat similar linguistic traits in different languages in a similar way – make RRG a good choice for a starting point in neurolinguistic research in which a ‘language universal’ neural substrate for language is a reasonable assumption. First, defining experimental conditions in notions that can be applied to all languages makes an experiment performable in other languages. Second, taken as a language processing model RRG itself makes predictions about different cognitive processes that are involved in various aspects of the grammatical theory. Namely, it is not difficult to choose a grammatical feature of a language, say, a number system, gender or person marking on verbs, and to build 100 sentences with a grammatical error that involves one of the mentioned features. The number of possible experiments corresponds to the number of grammatical features in a language. However, without a linguistic theory it is not easy to interpret the obtained data or to treat the similar results in a similar fashion cross-linguistically.

RRG treats sentence as a layered structure (Figure 4). This structure is language universal. All languages make difference between predicating and non-predicating elements. In all languages predicating elements take arguments (and make difference between arguments and non-arguments). The sentence structure thus has three levels: (a) *nucleus* (predicate), (b) *core* (predicate + arguments) and (c) *clause* (predicate + arguments + periphery (non-arguments)). In a sentence *Student reads a book in the library student* and *book* are arguments of the predicate while *in the library* is not an argument of the verb *read* and belongs to the periphery of the clause. The core arguments are only the arguments that are part of the semantic representation of the verb (see below). In this case, the verb *read* has two arguments that correspond to the traditional notions of subject and object.

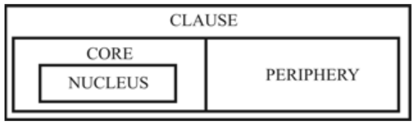

Figure 4. The layered structure of the clause

The layered structure of the clause defines relations between the main constituents of the sentence. The variety of possible structures is given in the '*syntactic inventory*' as 'syntactic templates'. Generally, they are of the form shown on Figure 5.

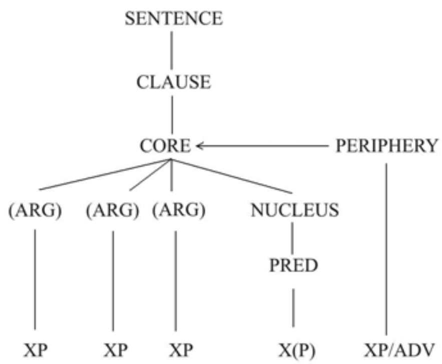

Figure 5. The constituent projection of a sentence

Some elements of a sentence might not be attached to anything in the constituent projection (see Figure 6). These elements modify a sentence or its parts and constitute qualitatively different grammatical categories. They are called *operators* and include grammatical categories such as tense or aspect, negation or illocutionary force. Operators modify different elements of the sentence; aspect modifies the nucleus, negation can modify nucleus, core or a clause, tense modifies the clause, etc. Operators are represented on a separate projection. Figure 6 shows a sentence in Croatian with both constituent and operator projection.

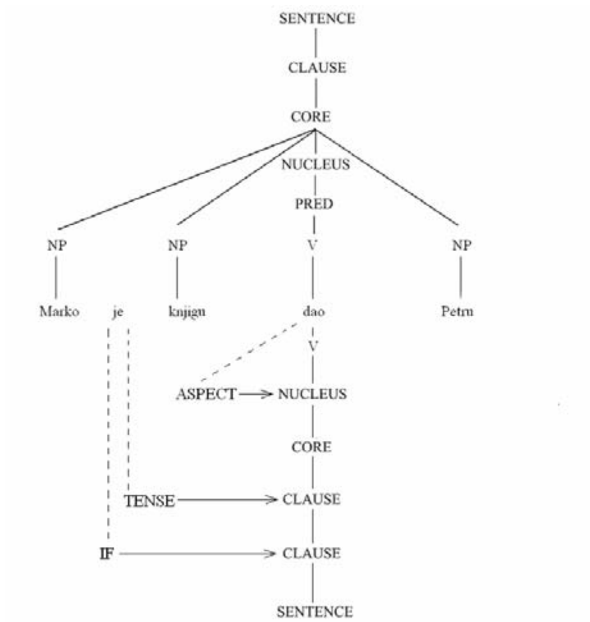

Figure 6. A sentence with both constituent and operator projection

Layered structure of the clause implies an important distinction between predicating and non-predicating elements (and among non-predicating elements between arguments and non-arguments). The distinction plays a role in semantic representation of the sentence. Verbal meaning is analyzed into 'semantic primitives' – a sort of semantic meta-language. This system of lexical decomposition is based on the distinctions in *Aktionsart* proposed by Vendler (1967). On the basis of lexical decomposition Vendler distinguished four verbal classes: *state* verbs, *accomplishment* verbs, *achievement* verbs and *action* verbs. These four classes are defined in terms of three features (Van Valin, LaPolla, 1997: 92), [static±], [punctual±] and [telic±]. *Static* verbs are verbs that refer to a state, e.g. *to love*, *to be tall* or *to have*. *Punctual* verbs refer to an action that happens in a moment, such as *break*, *explode* or *pop*. *Telic* verbs refer to an action with a terminal point, such as *dry* or *freeze*. *Accomplishment* and *achievement* verbs differ in this respect: while both refer to an action that is telic, only *achievement* verbs are also punctual.

Activity verbs, in contrast, refer to an action that is neither punctual, nor telic (e.g. *walk*, *eat*).

These four classes capture the verbs that refer to spontaneous actions. To capture the meaning of the verbs that refer to the action that is induced, Van Valin & LaPolla (1997: 97) introduce causative correlates of the four *Aktionsarten*. To account the fact that some verbs behave like activity verbs when they have a non-specific object or a mass noun as an object (e.g. beer, wine) and as accomplishment verbs when they have a quantified object (e.g. a glass of beer, a glass of wine), a new category, *active accomplishment* is introduced. Together with its causative counterpart, this makes the total of ten verbal classes. Each of these categories has a distinct logical structure as shown on Table 1.

Table 1. *Aktionsart* types and their logical structures

Verb class	*Logical structure*
State	**predicate'** (x) or (x, y)
Activity	**do'** (x [**predicate'** (x) or (x, y)])
Achievement	INGR **predicate'** (x) or (x, y)
	INGR **do'** (x [**predicate'** (x) or (x, y)])
Accomplishment	BECOME **predicate'** (x) or (x, y)
	BECOME **do'** (x [**predicate'** (x) or (x, y)])
Active accomplishment	**do'** (x [**$predicate_1$'** (x, (y))]) & BECOME **$predicate_2$'** (z, x) or (y)
Causative	α CAUSE β, where α and β are of any logical structure

The syntax-to-semantics linking – what, in fact, sentence comprehension is made of – is based on the logical structure of the verb. The linking consists of defining relations between the arguments in the logical structure and thematic relations, in RRG generalized thematic relations called 'macroroles'. There are two macroroles, '*actor*' and '*undergoer*' that are generalized agent-like and patient-like thematic roles, respectably. The linking algorithm is defined by the macrorole hierarchy (see Figure 7).

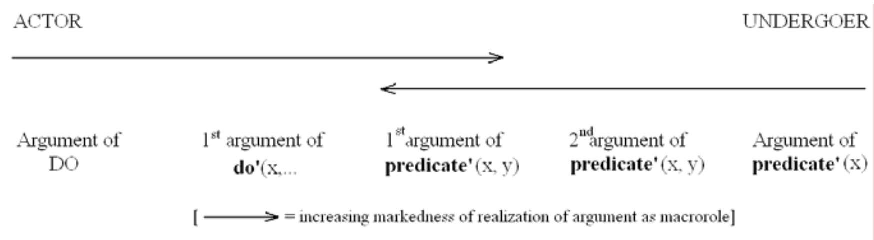

Figure 7. The macrorole hierarchy (Van Valin, LaPolla, 1997: 146)

The macrorole hierarchy specifies the actor and the undergoer arguments of the verb on the basis of the position in the logical structure (roughly, whether it is the 1st argument of **do'** or the 2nd argument of **predicate'**). This way in an active English (or Croatian) sentence the first argument of the verb (traditionally called 'the subject') is linked to the actor macrorole while the second argument is linked to the undergoer argument ('the object'). Languages differ in the linking pattern: ergative languages take the opposite linking pattern. But whatever the linking pattern be, the fact that it is somehow fixed (defined by the macrorole hierarchy) in fact makes sentence comprehension possible.

1.3.2. RRG as a sentence-processing model

The structure of RRG with syntactic representation on one side, semantic representation on the other side and a syntax-to-semantics interface between them allows for taking linguistic theory as a model of language processing (Van Valin, 2003a). Language production, as described in RRG, is actually parallel to the Levelt's *blueprint of the speaker* (Levelt, 1989). As Van Valin (2003a) notes, the Levelt's model is based upon vast psycholinguistic evidence, while the RRG linking algorithm is based upon grammatical evidence from a large number of typologically diverse languages. Yet each step in Levelt's model perfectly parallels steps in the RRG model of language production, which is strong evidence in favor of both. As for the comprehension, it is admitted that the syntax-to-semantics linking is psycholinguistically not plausible: according to the procedure, the output of the parser is a labeled tree structure upon which the linking rules are applied. However, it is common knowledge that the listener does not wait until the end of the sentence to start its interpretation. Therefore, the 'pseudosyntax' approach is adopted (originally proposed in Townsend & Bever 2001). The concept of pseudosyntax is equivalent to the shallow parsing described above: interpretation of the sentence starts before the sentence is completed and the thematic relations are assigned to the recognized constituents as soon as possible.

This line of thought is not followed in the Extended Argument Dependancy Model (eADM) developed by Bornkessel and Schlesewsky (in press). This model explicitly adopts some key concepts of RRG, but is, in fact, a three-phase serial model that strongly resembles Friederici's model. ELAN is thus related to 'template activation', LAN, P600 and N400 to computations related to linking between syntax and semantics, while world knowledge interference as well as repair or reinterpretation processes are represented in 'late postitivity'. The different processes within each of the three phases are parallel. Some basic concepts of RRG are not mentioned in eADM, the difference between constituent and operator projection, for example. An opportunity to find empirical evidence in favor of the 'psychological reality' of RRG is thus lost in eADM because according to RRG processes related to the two projections should be different. The only advantage of eADM over Friederici's model can be seen in the inclusion of results obtained in different languages which is possible when universally valid concepts of RRG are used as analytic tools. Communication-and-cognition perspective is also blurred (to say the least) in eADM. It is difficult to see how contextual, pragmatic or discourse information fits into the model.

1.4. Specific Language Impairment and Language Processing

1.4.1. Definition and classification of SLI

Specific Language Impairment seems to be a language disorder that eludes clear definition. It usually includes inclusion and exclusion criteria (Leonard, 1998). While inclusion criteria are less problematic and consist of scores on standardized language tests, the exclusion criteria bring about questions about the 'true nature' or causes of the Specific Language Impairment. SLI is thus defined as a language impairment that is not caused by perceptual handicap, intellectual deficits, motor disorders, neurological dysfunctions or by emotional or behavioral problems (Stark & Tallal, 1981). It is estimated that the prevalence of SLI is about 7% (Leonard, 1998). The estimation of the prevalence of SLI depends on the diagnostic criteria or tests used in diagnostic purposes. If, for example, SLI is diagnosed when the test scores are 2 standard deviations below mean, the prevalence of SLI will be 3% (Bishop, 1997). Bishop adds that the estimates also depend upon the tests being used and that

> …in practice, most children who are seen clinically and recruited for research studies will meet dual criterion that (1) a parent or teacher is concerned about

language functioning and (2) scores on a language measure are statistically abnormal, probably at least one SD below the mean (Bishop, 1997: 27).

If 1 SD below the mean is taken as a criterion, the prevalence will rise to 16%. Johnson et al. (1999) compared psychometric criteria and practitioners' ratings and found that 10,5% 5-year old children met the psychometric criteria, but only 6,7% of them actually met the practitioners' ones. The 7% criterion is, therefore, a good estimate of actual diagnostic practice and falls within the range defined by the scores 1 to 2 SD below the mean, if standardized tests are available.

Defining SLI as impairment in absence of any perceptual, cognitive or neurological deficit necessarily leads to the question about the cause of the impairment and imply theoretical questions about the nature of the wiring of language in the brain. On the theoretical level the existence of pure language deficit became an argument for the modularity of language. This sort of research often aimed at establishing a double dissociation between language and other cognitive abilities in SLI and Williams Syndrome (e.g. Clahsen & Almazan, 2001 or Pléh et al. 2002, but see Stojanovik et al., 2004 for the opposite view). Double dissociation (SLI: poor language, normal IQ vs. WS: normal language, poor IQ) was considered as an argument in favor of a generativist view of language. If language ability alone can be affected or speared, language could be regarded as a separate, 'encapsulated' cognitive function. However, many studies in SLI reveal weaknesses in other, non-linguistic areas such as motor skills, mental imagery or mathematics. For example, a study by Bishop and Edmundson (1987) showed that 22% of SLI children included in their study had 'global cognitive delays'. In addition, it is well known that SLI children do not constitute a homogenous group. Language abilities were also compared across different populations to establish similarities and dissimilarities in language function between children with SLI and e.g. Autism or Down Syndrom (Bishop & Frazier-Norbury, 2002; Laws & Bishop, 2003) with a different *rationale*: to show how some non-linguistic deficit (in these articles 'general information processing') affects language function in a similar fashion in different deficits exactly because the underlying deficit in SLI is more general and not language specific. Similar approach is adopted in the 'critical mass' approach of Conti-Ramsden & Jones (1997). The lexicon limitations simply do not allow children with SLI to make rules, i.e. it is due to the general learning mechanism failure that the children need bigger vocabulary to extract rules; therefore, morphology (especially verb morphology) is affected although the core of the deficit lies somewhere else.

Heterogeneity of SLI is notorious (although for opposite view see e.g. Schöler & Fromm, 1996). However, there is even less agreement about the classification of subgroups of SLI than about its definition. Reviewing the literature Fletcher (1992) suggests three criteria for classification: clinical, psychometric and linguistic. Other researchers usually confront two criteria, clinical and psychometric (e.g. Conti-Ramsden & Adams, 1995, Conti-Ramsden et al., 1997, Leonard, 1998). As the names imply, psychometric (or 'cluster analysis') criteria define subgroups based on different outcomes on various language and non-language tests. The tests usually cover articulation, receptive and expressive vocabulary and aspects of receptive and expressive grammar. Word and non-word repetition as well as sentence repetition is often included. Recently, narrative tests are included, as well (e.g. the Bus Story). The two most detailed classifications were suggested by Rapin and Allen (1987) and Conti-Ramsden et al. (1997) and divide SLI children into six subgroups (see a simplified overview on Table 2).

Table 2. The subgroups of SLI (according to Conti-Ramsden, 1997)

	AFFECTED (Conti-Ramsden, 1997):	SUBGROUP (Rapin & Allen classification):
1	Fair vocabulary, all other tests poor	Lexical-syntactic deficit syndrome
2	Fair to good at all tests except word reading	No match
3	Good vocabulary, poor at all other tests, expressive difficulties	Verbal dyspraxia
4	Good at TROG*, fair at voc., Bus Story, articulation and number skills, poor at word reading	Phonologic programming deficit syndrome
5	Fair at articulation tests, poor at all other tests	Phonologic-syntactic deficit syndrome
6	Good at articulation and word reading, good voc., fair TROG and Bus Story, poor number skills	Semantic-Pragmatic deficit syndrome

*TROG = Test for Reception of Grammar, Bishop, 1982.

The classification that is widely used is the one given in the DSM-IV (2000) although in this manual the term ‘Specific Language Impairment’ does not appear. Language impairments are classified under Axis I, under chapter ‘Disorders Usually First Diagnosed in Infancy, Childhood or Adolescence’ if no other general medical (e.g. neurological) condition is present (the disorder is then coded on Axis III). This constraint amounts to the exclusion criteria in the definition of SLI. The language impairments are classified under ‘Communication Disorders’ as Expressive Language Disorder (code 315.31), Mixed Receptive-Expressive Language Disorder (315.32) and Phonological Disorder (315.39). Their diagnosis depends on test scores, if available. If standardized tests are not available, the diagnosis should be based on ‘functional assessment of the individual’s language ability’ (p. 58). This classification is very close to the frequently used clinical descriptions of SLI (Conti-Ramsden & Botting, 2001). According to these SLI is divided into the expressive-receptive (ER-SLI), expressive (E-SLI) and ‘complex’

(C-SLI). Children with C-SLI have difficulties with understanding, but also with the social use of language. This is sometimes referred to as ‘pragmatic’ language impairment that is ‘autism-like’ (Bishop & Frazier Norbury, 2005).

Linguistic classification of SLI is the most disputable. It is usually driven by the linguistic theory and often reflects theoretic views of the researcher who suggests it. In addition, it is influenced by the language that is being researched. Finally, it is hardly a classification at all. It is more precise to speak about linguistic account of SLI than about linguistic classification because it is usually one feature that is singled out as the core of the deficit with some elements of the language system being more or less affected by it (depending on what is taken as the deficit or particular language).

One of the first linguistic accounts of SLI was the Extended Optional Infinitive Account (Rice et al., 1995). While younger children with typical language development pass the ‘optional infinitive’ phase in which they omit morphological markers on verbs, SLI children treat morphological marking as ‘optional’, not obligatory for an extended period of time. Other linguistic accounts of SLI follow this line of reasoning, but place the source of the deficit somewhere else. For example, Clahsen (1989) proposed the Missing Agreement Hypothesis claiming that the source of the deficit lies in the child’s inability to establish agreement relations in a sentence. The hypothesis was based on observation of German children with SLI who had problems especially in number and gender agreement on articles and determiners. Similar reasoning was applied in van der Lely’s account of SLI, as well. She tries to apply generativist framework (Government &

Binding, to be more precise) to explain language deficits in SLI children claiming that the source of the deficit lies in the inability of SLI children to assign correct thematic roles to arguments (van der Lely & Stollwerk, 1997). This explains wrong choices of case markers or difficulties in understanding of passive sentences in English (inverse word order with reverses thematic role assignments). In recent articles (van der Lely & Battell, 2003) she tries to explain the core deficit in SLI within the 'Minimalist program' (Chomsky, 1995) claiming that it is the movement rule that is affected in SLI.

1.4.2. Approaches to SLI

Common denominator of these 'linguistic' approaches is the claim that the source of the deficit lies on the representational level, not on the processing one. This makes such approaches highly controversial, to say the least: for example, according to the Extended Optional Infinitive Account there should not be SLI in Croatian at all because there are no optional infinitives in the first place.

There are several ways to classify theoretical approaches to SLI. Leonard (1998) provides the most detailed classification. He divides theoretical accounts of SLI into three groups: (i) SLI as a deficit in linguistic knowledge, (ii) SLI as a processing deficit in specific mechanisms, and (iii) SLI as a limitation in general processing capacity. The first group comprises of the theoretical accounts already described: a search for the deficit in the grammatical system is common to these approaches. It is a 'missing rule' account. Other two theoretical accounts have one common characteristic: they see SLI as a processing problem. If specific, this processing can be linguistic in nature (i.e. phonological, as in Montgomery & Leonard, 1998, McGregor & Leonard, 1994, Leonard, 1995, Owen & Leonard 2006, Ziegler et al., 2005). According to this view, deficits in processing phonological information cause an avalanche effect in other language areas; the least salient grammatical markers are most vulnerable. The deficit can also be non-linguistic: the core of the impairment might be a working memory deficit (Montgomery, 1995, Weismer et al., 1999, Newbury et al., 2005, Schöler, 1993). It can be further located in the phonological loop (Schöler, 2000), or it can be viewed as a deficit in the speed of memory scanning as in Sininger et al. (1989); or a deficit in processing rapid acoustic signals (Tallal, 1976, Tallal et al., 1985, Wright et al., 1997). Finally, the third view takes SLI to be a general processing deficit (Weismer & Evans, 2002). This view is also known as Generalized Slowing Hypothesis (e.g. Kail, 1994, for review of the literature see Hill, 2001). Emphasis is put on the non-linguistic tasks in which SLI children perform poorer than their typically developing peers. Language impairment thus reflects some general component of cognitive processing that is impaired in SLI children.

1.4.3. SLI studies using Event-Related Potentials

The method of ERP could provide better insight into the 'nature' of SLI offering a new tool for testing various hypotheses about the causes of the impairment. Generally, the developmental studies using ERP are rare. Studies such as widely discussed Molfese et al., (2003) in which more than one hundred children were included are really rare.

ERP has been used in study of SLI in two ways: to establish the precursors of SLI in pre-linguistic infants and toddlers (Weber & Friederici, 2004, Weber et al., 2005) or to define the changes in language related components (or auditory perception related components) in the population of children with SLI (e.g. Ors et al. 2002, McArthur & Bishop, 2005). The results of these research falls into two groups regarding the possible explanation of SLI; while research oriented towards infants (age 5 months) at-risk revealed differences in the mismatch negativity (MMN), in experiments performed by McArthur and Bishop on SLI children (age around 13) a difference in N1-P2-N2 components were found. As the MMN can be related to memory trace processes (Näätänen et al., 2005), this could lead to memory-based explanation of SLI. McArthur and Bishop's findings speak in favor of the deficit in rapid auditory stimuli processing as well as the findings in the Ors et al. (2002) in which a delay in P300 latency for auditory stimuli in parents of SLI children was found. However, these findings are not conclusive: they are all restricted either to non-language stimuli (tones of different frequencies or spectrum) or very simple language stimuli suitable for the oddball paradigm (syllables, for example). A paradigm with sentences was used in an experiment by Heather van der Lely (van der Lely & Fonteneau, 2003). She claimed that instead of syntax related LAN and P600, SLI children showed difference in N400. This would amount to some sort of asyntactic comprehension that would be a characteristic of her controversial G-SLI group. In a study by Kaan et al. (2000) a well known difficulty with filler-gap constructions was examined and a significantly latter onset of the P600 was found in children with developmental language impairment.

1.5. Language Processing Research in Croatian

Sentence comprehension studies that use any of the on-line methods are quite rare in Croatian. In fact, only one study on sentence comprehension in Croatian is available (Mimica et al., 1994). The study is aimed at establishing cue strength of case markings, word order and agreement in Croatian using reaction times. A developmental study in the connectionist framework has been done, as well (Kuvač & Cvikić, in press). It provides a closer look at Croatian noun morphology defining morphological cues, their strengths and validity in normal language development. Older studies did not employ on-line methods. Some of them were inspired with generativist ideas (Fulgosi, 1979) and were aimed both on explaining processing involved in sentence comprehension and lexical retrieval. Some of them were crucial for introducing psycholinguistics to Croatian academic community and for initializing empirical research in language processing by collecting first spoken language corpus (Stančić & Ljubešić, 1994, Vuletić, 1991).

SLI has been a subject of more thorough research (e.g. Kovačević, Ljubešić, 1997, 1995, Schöler et al., 1998, Kovačević, 1997, Kovačević et al., 1997), covering many aspects of the deficit: short-term memory, metalinguistic knowledge, morphology and syntax, etc. The first research project that was particularly focused on language and not speech impairments was initiated in the *Cabinet for Early Communication* of the *Center for Rehabilitation* of the Faculty for Special Education and Rehabilitation in Zagreb. Within this project KIDS (*Kent inventory of developing skills*) (Reuter et al., 2000) was adopted. Children with language impairment who enter elementary schools were subject of this research project, as well. The project covered several aspects of language function in children. (Ljubešić, 1997). The research included studies of reading and writing abilities of SLI children, learning (and other cognitive) difficulties, syntax and narrative abilities as well as social and psychological aspects of language impairments.

Typical and impaired language processing and language development across populations of typically developing children and children with SLI was studied in a recent national research project of the Laboratory for Psycholinguistic Research (0013002). The project aimed at establishing norms of typical course of language development in Croatian and resulted in adopting and standardizing Peabody Picture Vocabulary Test (PPVT, Kovačević et al., in press) and McArthur-Bates Communicative Development Inventories (CDI, Kovačević et al., 2005). The project had a cross-linguistic perspective, especially in the segment which was included in the international project of the Austrian Academy of Science (*Pre- and Protomorphology in Language Acquisition*) initiated by Wolfgang Dressler (Kovačević et al., 1996, Anđel et al., 2000, Jelaska et al., 2002). Aphasia was also studied (Vuletić, 1996) with focus being made on the description of the affected language subsystems as well as on the rehabilitation of the affected individuals.

Child language research in Croatian has been a subject of thorough research and was approached from different angles – from psychology, pedagogy and language & speech pathology to theoretical and applied linguistics and phonetics. The research can be traced back in the nineteen sixties when the research was based on diary data (Furlan, 1963). In the seventies a national project on establishing norms of child language development aimed at obtaining and analyzing first records of child language. The project did not result in establishing language development norms, but it was important for collecting first experiences in building child language corpora and for collecting and analyzing acoustic features of early child language (Škarić, 1973).

Until recently no electrophysiological method in language processing research has been used. The first ERP studies of language comprehension started within the *Language Communication & Cognitive Neuroscience* program (Dobravac & Išgum., 2004, Palmović et al., 2004). In these studies the aim was set very low: to obtain basic ERP components related to various aspects of syntactic and semantic processes involved in language comprehension (LAN, P600, N400). For now, no language impairment studies have been published, although Croatian could surely provide an interesting insight in a number of phenomena. Dyslexia could be a good candidate. For a comparison, in a study of dyslexia (Csépe et al., 2003) early ERP components do not differ between words and pseudo-words (as it could be expected) due to the transparent Hungarian orthography. Since Croatian orthography is even more transparent than Hungarian, similar results could be expected.

2. AIMS AND PROBLEMS

There are two main aims to be achieved in this thesis:

(1) to define electrophysiological correlates of various elements of sentence comprehension in Croatian and

(2) to define differences in sentence processing in language development, i.e. to find differences in ERP signature of sentence processing between (a) adults and children with typical language development (TLD) and, (b) between children with TLD and children with Specific Language Impairment.

2.1. Evidence for Sentence Comprehension

An attempt to dissociate various elements of syntax processing will be made. These elements will be defined along the theoretical distinctions formulated in the Role and Reference Grammar (the distinction between the constituent and operator projection of the clause). Therefore, since Role and Reference Grammar operates with language universal notions, the established dissociation will tackle the problem of sentence processing on a universal, not language specific level, i.e. the results could be used for predicting the results in other languages.

The dissociation between various elements of syntax processing calls for a reinterpretation of the syntax-to-semantics interface that makes the core of the comprehension process.

2.2. Sentence Comprehension in Typically Developing Children and Children with Specific Language Impairment

Behavioral studies of language comprehension in child language development and in the population of children with developmental disorders are excellent tools for defining the developmental trajectories of particular language features and for detecting particular strengths and weaknesses of children with language disorders. However, behavioral studies provide insight only into the results of sentence processing, not in the processing itself. It is the aim of this study to gather ERP data on sentence processing in typically developing children in order to obtain possible evidence for differences in language processing between adults and TLD children, i.e. to obtain basic developmental data on sentence processing in Croatian. The differences obtained in terms of ERP components could perhaps be attributed to developmental changes related to the process of language acquisition. The information obtained in the group of TLD children will be compared to the data collected in a group of children with SLI. The data collected in a group of TLD children and SLI children will be used in the discussion about the problem of the nature of SLI. Using the theoretical distinctions between various parts of syntax, as defined in RRG, in the experiments with SLI children allows for the interpretation of the results in terms of syntax-to-semantics interface and its relation to language development, rather than just defining language specific grammatical strengths and weaknesses of SLI children.

3. HYPOTHESES

The hypotheses can be grouped according to the two main aims:

1. Evidence for Sentence Comprehension

H1.1 In a group of adult speakers different aspects of syntax, case and tense, in a process of sentence comprehension will elicit different electrophysiological response.

H1.1.1. Case violation will elicit left anterior negativity (LAN) and late positivity (P600) reflecting the error on the constituent projection of the clause.

H1.1.2. Tense violation will not elicit LAN, while eliciting P600 reflecting the error on the operator projection of the clause.

H1.2. In a group of adult speakers on a noun phrase level different electrophysiological responses will be elicited between quantifier and gender violation.

H1.2.1. Gender violation will elicit LAN and P600 effects that reflect the detection of agreement error.

H1.2.2. Violation in quantifier will trigger different word expectations thus eliciting N400 component.

2. Sentence Comprehension in Typically Developing Children and Children With Specific Language Impairment

H2.1. In a group of children with typical language development (TLD) no difference in electrophysiological response with respect to adults is expected.

H2.1.1. Case violation will elicit LAN and P600 while tense violation will elicit P600 effect.

H2.2. In a group of children with SLI the electrophysiological response reflecting sentence comprehension will differ from the response obtained in a group of TLD children.

H2.2.1. The difference will consist of the shift in latency for the LAN and P600 components in the case experiment.

H2.2.2. The difference will consist of the shift in latency for the P600 component in the tense experiment.

H2.3. It is not expected that the electrophysiological response of children with SLI will differ only on one experiment reflecting affectedness of only one grammatical subsystem (constituency or operators).

4. METHODS

4.1. Participants

There were four groups of participants included in the study.

a. The first group was a group of healthy adults (N=23). They took part in the experiments aimed at obtaining data on sentence comprehension in Croatian. All participants were students of psychology and language & speech pathology, 3rd and 4th year. All participants were right-handed with normal or corrected-to-normal vision. None of them reported any neurological problem or had a history of neurological diseases. Initially, 26 participants took part in the experiments, but the data obtained from three participants had to be excluded due to the high level of noise. The group of adult participants thus consisted of 23 participants, (for male participants N = 5 and for female N = 18). Out of them, ten participants (males: N = 3, females: N = 7) took part in the additional experiments. The mean age was 23 with the standard deviation of 2,1.

b. The second group of participants was a group of SLI children (N=4) selected on the basis of previous data collected mainly at the Clinical Research Unit of the Laboratory for Psycholinguistic Research. However, each child was tested on a number of tests to confirm the diagnosis and to establish whether a child met the exclusion criteria or not. A relatively small number of children with SLI was chosen in order to obtain as homogenous group of SLI participants as possible. All children were included in therapy either in the *Clinical Research Unit* of the Laboratory or in the *Center for Rehabilitation* of the Faculty for Special Education and Rehabilitation.

On the basis of the test results 6 SLI children of age 9 to 11 were selected (5 boys 1 girl, average age 9;11). However, EEG data from two children (two boys) had to be rejected due to the artifacts and noise. The number of children was thus reduced to four (three boys and one girl). The girl has difficulties mostly in the area of morphology and semantics. Two boys achieved lower scores on the phonological tests. In one case the language and speech pathologist reported phonological difficulties affected strongly other aspects of language (i.e. although the overall results were low, the core of the impairment was phonological). Finally, one boy has lexical-semantic impairment.

c. The third group comprises of the children with typical language development (TLD children, N=9). It consists of children who match to SLI children in age (three boys six girls; average age = 10, SD=1,2).

d. Finally, *the fourth group* of participants was a group of adults (N=10) included in the experiments aimed at collecting data from TLD and SLI children, as a control (since the experiments were slightly changed in order to make them more suitable for children, as explained in the next paragraph). This group different from the first group of participants (adults) and took part only in the experiments with children. The group consists of psychology and language & speech pathology students of the 3rd and 4th grade (three males, seven females; average age 22). Permission for the study was obtained from the Ethical Board and all participants gave a written informed consent. The informed consent for children was signed by their parents.

4.2. Experimental Design

4.2.1. ERP experiments

In order to confirm or reject the given hypotheses the total of six experiments were conducted. In these experiments a difference in the electrophysiological response between conditions is sought for. In addition, the results between the three groups of participants were compared. This made the overall design of the study somehow complicated. Figure 8 shows an overview of the design with 'X' designating the experiment, in which a particular group of participants took part, and with lines showing which experiments (i.e. their results) will be compared and which groups of participants will be compared. In each experiment there are two conditions: the *violation* and the *non-violation* condition.

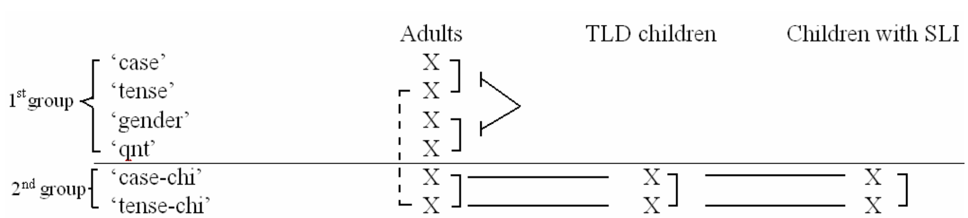

Figure 8. The overview of the experiments and their participants

The experiments listed on Figure 8 are named after the target word, i.e. after the violation condition. In the '*case*' experiment there is a violation in case, in the '*tense*' experiment there is a violation in tense, etc. The experiments performed on children are named '*case-chi*' and '*tense-chi*'.

As shown on Figure 8, the six experiments fall into two categories regarding the experimental design: the first four experiments utilize the within-group design in which data collected within a group of adult Croatian speakers are compared in the two main and two additional experiments in order to find the differences between the two kinds of syntactic processes on the different projections of the clause. In the remaining two experiments a between-group design was applied in order to find differences between the three groups of participants.

4.2.2. The first group of experiments

Experiment 1('case'). The experiment consists of 200 four-word sentences (phonological word, as explained below) with a target word in the final position in the sentence. All sentences are built around a transitive verb that requires an argument in Accusative (i.e. all verbs are, in RRG concepts, M-transitive - they have actor and undergoer arguments). In half of the sentences (i.e. in the violation condition) the last word, a noun, was put in the wrong case, the Dative as in the following glossed example taken from the stimulus sentences:

(19)	*Učenik-Ø*	*je*	*lani*	*pročita-o*	*lektir-i.*
	Pupil-Nom.Sg.	*AUX*	*last year*	*read-masc.sg*	*reading-Dat.Sg.*

'The pupil has read the reading last year.'

Figure 9 shows how Dative instead of Accusative violates the constituent projection of the clause.

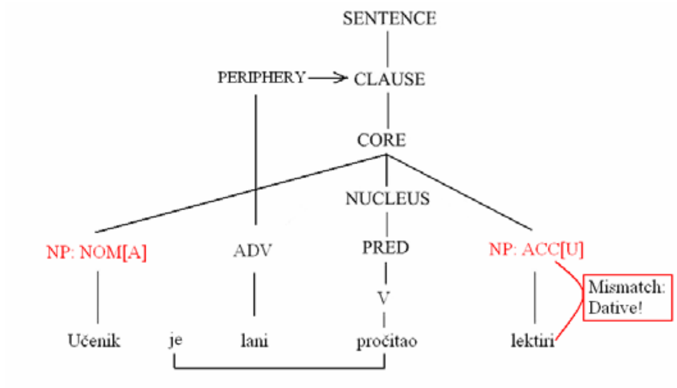

Figure 9. A mismatch on the constituent projection

In the *non-violation* condition the target word was in Accusative as required by the constituent structure:

(20) Novin-e su jako hvalil-e izložb-u.

Newspaper-Nom.Pl. AUX strongly commend-Pres.3Pl. exibition-Acc.Sg.

'The newspaper strongly commended the exhibition.'

All target words were selected from the Croatian frequency dictionary (Moguš et al., 1999) and fall into the frequency range from ≈2500 to ≈600 words in 1.000.000 words (the most frequent words according to Moguš et al., 1999). All target words consist of three syllables. Phonological difficulty was also accounted for in terms of absence of consonant clusters longer than two phonemes. As the case is manipulated in the experiment, the experiment will be referred to as the '*case*' experiment.

The sentences were presented to the participants visually in a word-by-word manner. Each word was in the middle of the 19'' computer screen for 600 ms. Each word was written in Times New Roman, the font size was 48 and its color was black. The background was white. The participants were sitting at a distance of around 1 m from the screen. The inter-stimulus interval (ISI) was 1100 ms (v. Figure 10).

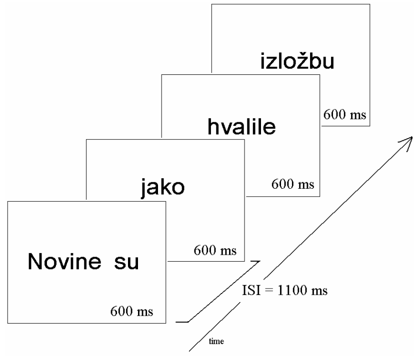

Figure 10. The presentation of the stimulus sentences

Each sentence (i.e. the last word of the preceding sentence and the first word of the following sentence) was separated by the 1700 ms interval. Each computer slide consisted of one word. However, in the first slide the auxiliary verb came together with the noun, the subject of the sentence. As the clitic has to come right after the first word in a sentence, the canonical position of the auxiliary verb was thus preserved. It is pronounced together with the first word as one word (a word with its clitic is one phonological word). If the auxiliary were on a separate slide, it would have been read with an accent, which is ungrammatical and unnatural even when the reader reads silently. Therefore, throughout the stimulus sentences the clitics were always presented together with the word which carried the accent. Every 20 – 25 sentences a pause was inserted (a yellow circle on the screen followed by the cross (+) to prepare the subject for the continuation of the experiment). Each pause lasts 10 seconds during which the participants were instructed to blink freely or move head. This was necessary because it took 25 minutes to complete the experiment and, initially, without the pauses the participants felt friction and the loss of concentration. The participants were asked to make grammaticality judgments by pressing one of two buttons on the response pad.

Experiment 2('tense'). The experiment was similar in every detail, but the target word. The experiment consists of 200 sentences, one hundred in *violation* and one hundred in *non-violation* condition. Each sentence consists of four (phonological) words with the target word in the sentence final position. The experiment manipulates two tenses: future and past tense. Future tense is built with the clitic present form of the auxiliary verb 'to have' and the main verb in Infinitive. Past tense is build with the clitic present form of the auxiliary verb 'to be' and the main verb in Participle. Every verb in Croatian has two stems: present and infinitive. As both Infinitive and Participle are built from the infinitive stem, the target words differ only in the final morpheme. Since the tense is manipulated in the experiment, it will be referred to as the '*tense*' experiment.

The *non-violation* condition consists of 100 sentences. Every sentence begins with the subject followed by the auxiliary verb. They form one phonological word. Temporal adverb or adverbs and/or the object follow. Finally, the main verb in Infinitive or Participle occupies the final position in the sentence. Half of the sentences were in the past tense, while the other half in the future tense. The glossed example shows a *non-violation* condition sentence taken from the stimulus set:

(21) Zvon-a će sutra u podne zazvoni-ti.

Bell-Nom.Pl. AUX tomorrow at noon ring-Inf.

'The bells will ring tomorrow at noon.'

The auxiliary verb defines the tense, i.e. makes the expectations regarding the form of the main verb. If it is *će* (3rd person Pres. Sg. 'to have'), Infinitive is required, if it is *je* (3rd person Pres. Sg. 'to be'), Participle is required.

The *violation* condition consists of the same sentences with the violation in the final word. In half of the stimulus sentences the final word is Infinitive instead of Participle and in the other half vice versa as in the following example:

(22)	*Brod-Ø*	*će*	*sutra*	*sigurno*	*zaplovi-o.*
	Ship-Nom.Sg.	*AUX*	*tomorrow*	*surely*	*sail-masc.sg.*
	'A ship will tomorrow surely sailed away.'				

In the *violation* condition it is not the constituency that is violated. The violation is on the operator projection, as shown on Figure 11.

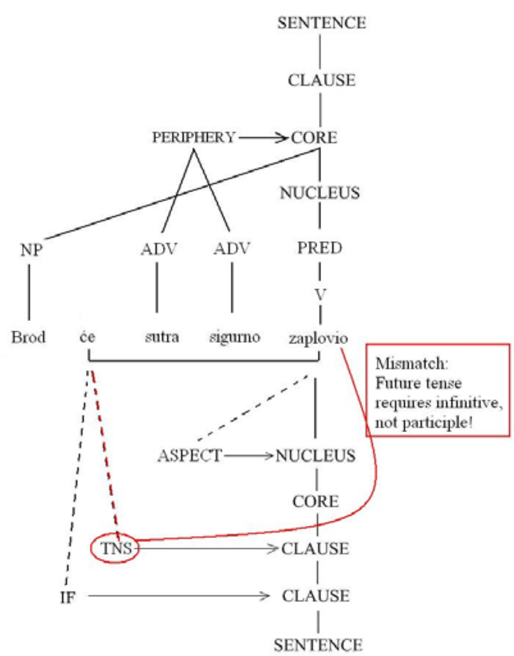

Figure 11. A mismatch on the operator projection

The procedure was the same as in the '*case*' experiment. The stimulus sentences were presented visually, in a word-by-word manner. Each slide consisted of one phonological word to achieve more natural presentation of the sentence. Each slide was shown for 600 ms with 1100 ms ISI. The sentences were separated by an interval of 1700 ms. After each 20-25 sentences pauses were added to reduce fatigue and allow participants to blink frequently or move. In both conditions the final words were equalized in terms of frequency according to the Croatian frequency dictionary in the same way as in the '*case*' experiment (Moguš et al., 1999). They were also equalized in terms of number of syllables and phonological difficulty (absence of consonant clusters longer than two phonemes). The only difference between the '*case*' and '*tense*' experiment is the word order. In the '*tense*' experiment the word order is not canonical. This makes the stimulus sentences more unnatural than the '*case*' experiment sentences. However, relatively free word order in Croatian in general and paying attention to the sentence focus (mainly by the choice of the adverb) reduced this unnaturalness of the stimulus sentences. Again, the participants were asked to make grammaticality judgments by pressing one of two buttons on the response pad.

Experiment 3 ('gender'). This is an additional experiment aimed to show the difference in language processing on a level lower than the sentence, i.e. on a noun phrase level. It consists of 200 word pairs, adjectives and nouns (Adj. + N.). As adjectives have to agree in gender with the nouns they modify, the violation in agreement simply consists of mismatch between the gender of the adjective and the noun as in (23):

(23)	*mal-i*	*kuć-a*
	small-Masc:Nom:Sg	*hause-Fem:Nom:Sg*
	'small house'	

In Croatian adjectives usually precede the nouns; therefore nouns were chosen as the target words. They are all of the similar frequency (from ≈2500 to ≈600 in 1.000.000 words, according to Moguš et al., 1999) and consist of two syllables. The stimuli were presented in a word-by-word manner, each word occurring for 600 ms with the 1100 ISI and 1700 ms between each noun phrase. After every 40-50 pairs a pause was inserted to allow participants more frequent blinking and head movements. As in the main experiments, the participants were asked to make grammaticality judgments by pressing one of two buttons on the response pad. Since the gender is manipulated in this experiment, it will be referred to as the '*gender*' experiment. It should be mentioned that, strictly speaking, adjectives themselves are defined as operators in RRG; therefore, the structure of the NP that consists of an adjective and a noun would be represented as

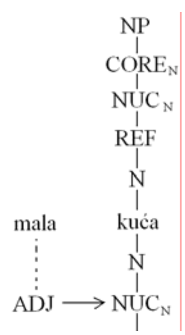

Figure 12. Layered structure of the noun phrase in RRG

However, gender of the adjective defines its agreement with the noun and if two nouns and two adjectives are combined, it is the gender that tells us which adjective agrees with which noun thus defining the constituency. Therefore, mismatch in gender is taken as a constituent error here. In addition, the newer versions of RRG (Van Valin, 2005) take adjectives to have analogous status to adverbs in the clause: they are periphery of the NP and thus belong to the constituent structure of the NP. Operators are now grammatical categories to which adjectives - as a lexical category - do not belong.

Experiment 4 ('quantifier'). The experiment consists of 200 word pairs and each pair consists of a cardinal number and a noun (Num. + N.). In 100 pairs the number precedes a countable noun (e.g. *stolac* 'chair' or *šljiva* 'plum') and in 100 pairs the number precedes a mass noun (i.e. an uncountable noun such as *meso* 'meat' or *voće* 'fruit'). This constitutes the *non-violation* and *violation* condition, respectively. In this experiment the quantifying of the noun is manipulated; therefore, the experiment will be referred to as the '*quantifier*' experiment. Since quantifiers are represented on the operator projection in RRG, a noun phrase in which a cardinal number precedes an uncountable noun contains a violation that can be traced to the operator projection of the NP.

All nouns consisted of two syllables and were chosen on the basis of their frequency (according to Moguš et al., 1999). The numbers were all monosyllabic (*dva* 'two', *tri* 'three', *pet* 'five' and *šest* 'six'. The stimuli were presented visually, in a word-by-word manner. The numbers were presented in letters. Each word was on the computer screen for 600 ms and the ISI was 1100 ms. The pairs were separated by 1700 ms interval. After each 40-50 pairs a pause was inserted to allow participants a short brake. The participants had to make the grammaticality judgment by pressing one of two buttons on the response pad after the second word (the noun).

4.2.3. The second group of experiments

Experiment 5. This experiment is very similar to the '*case*' experiment. It consists of 200 SVO sentences out of which 100 contain the target word in the wrong case (Dative instead of Accusative). The target word was the last word in the sentence (the direct object). This constitutes the violation of the constituent projection of the sentence. The difference between the '*case*' and this experiment is in its length. This experiment consists of three (phonological) words to make it more suitable for children and children with SLI. Therefore, it will be referred to as the '*case-chi*' experiment.

All target words are of the similar (high) frequency according to the Croatian frequency dictionary (Moguš et al., 1999). In addition, since the target population of the experiment is children and children with SLI, all target words were checked against the Croatian child language corpus (Kovačević, http://childes.psy.cmu.edu/data/Slavic) and only the words that could be found there were taken for the stimuli.

The stimulus sentences were presented visually, in a word-by-word manner. Each word was presented for 600 ms with the ISI of 1100 ms. The interval between the sentences was 1700 ms. After every 25-30 sentences a pause was inserted to allow participants more intensive blinking and head movements. The sequence file that contained all stimulus sentences was designed to allow for slowing down the procedure if necessary, i.e. if the children with SLI were not able to follow the sentences.

Experiment 6. This experiment differs from the '*tense*' experiment not only in its length, but also in the word order. While the stimulus sentences in the '*tense*' experiment had S-Adv-O-V order (with the last word being the target word), in this experiment it was SVO, the canonical word order in Croatian. As mentioned above, the reason for this change is based on the previous knowledge about linguistic abilities of SLI children. The change of word order strongly affects sentence comprehension in SLI children (Babić, 1995); therefore, child's failure to comprehend the stimulus sentence and a very probable problem of keeping the child's attention would definitely affect the measurements. Since the experiment is designed primarily for children, it will be referred to as the '*tense-chi*' experiment.

The experiment consists of 200 stimulus sentences. One hundred sentences have a violation in tense, i.e. a mismatch between the auxiliary and main verb, as in the '*tense*' experiment. The main verb follows the auxiliary verb, which is a clitic after the first word in the sentence (as described and prescribed in Croatian grammars, e.g. Katičić, 1986). The direct object follows the main verb. Therefore, each stimulus sentence consists of three (phonological) words: the subject and its clitic (auxiliary verb), the main verb and the object. The stimuli were presented visually in a word-by-word manner. Each word was presented for 600 ms with ISI of 1100 ms. The interval between the sentences was 1700 ms. The sequence file was designed to allow slowing down the sequence if the stimuli were too fast for SLI children. As in all other experiments, after each 35-40 sentences a pause was inserted to allow participants head movements and more intensive eye blinking. The participants were asked to make a grammaticality judgment after each sentence by pressing the button on the response pad.

4.2.4. Behavioral tests

Reaction time. Two kinds of behavioral tests were employed: reaction time was measured in all ERP experiments in order to keep the participants alert. However, in '*case*' and ‘*tense*’ experiments as well as in the additional ‘*gender*’ and ‘*quantifier*’ experiments reaction time data were measured separately, using E-prime software (Schneider et al., 2002). The reason for separate measurements of RT and ERP is a practical one: e-prime equipment used in the measurements has a very high level of precision (+/- 20 μs) and a more practical way of exporting data to a statistical program than the ERP equipment used in the experiments. In addition, e-prime RT data collection was used as a training session for the ERP experiment. The same kind of stimuli sentences (or word pairs) was used in RT measurements. However, the words were changed to avoid their repetition in the ERP experiments.

Verbal and non-verbal abilities tests. Verbal and non-verbal abilities tests were used to determine language status of SLI children in order to choose as homogenous group of SLI children as possible. At present these test materials are the best testing materials for establishing (and using) inclusion and exclusion of SLI children in Croatian. The testing materials used in this study were developed in the Laboratory for Psycholinguistic Research (Clinical Research Unit) as working materials for language disorder diagnostics. They were used for making a reliable profile of language abilities of SLI children. The tests materials examine phonological, morpho-syntactic and lexical skills of the children (v. Table 3 for an overview). In addition, Peabody Picture Vocabulary Test (PPVT) was administred. The PPVT has been standardized for Croatian (Kovačević et al., in press). Narrative abilities were assessed using The Bus Story (Renfrew, 1969). Employment of so many tests provided rather detailed information on all language components for each child involved in the study. However, as the tests were initially developed for pre-school age, consistent and valid scoring was not possible to achieve. Therefore, together with language & speech pathologists of the Clinical Research Unit a descriptive score was given for each child on each test (‘poor’ – ‘moderate’ – ‘good’) depending on how different the test results were in relation to the results achieved by their peers. The second reason for this sort of scoring arises from both how scoring of particular tests was designed and what kind of errors SLI children typically commit. Since these errors are typically different from errors of their TLD peers, child’s actual answer was recorded. Therefore, the overall achievement on a test could not be stated easily.

Table 3. The language variables tested in the study

	Phonology:	
Test materials:	Discrimination	Rapid naming
	Phonological analysis and synthesis; deletion of phonemes in words	Word Repetition: semantically similar words
	Phonological memory (forward and backward)	Pseudo-words repetition
		Word Repetition: phonologically similar words
	Morphology & Syntax	
Test materials:	Noun morphology: Case and number	Prepositions (comprehension & production)
	Verb morphology: prefixation	Possessive relations
	Sentence repetition	
	Lexicon & Semantics	
Test materials:	Lexical production	Antonyms, synonyms, homonyms
	Peabody Picture Vocabulary Test	
	Narrative abilities	
	The Bus Story	

Phonological abilities were tested on number of test materials.

a. Discrimination test in which a child was asked to discriminate between phonologically similar words by offering a definition for each pair (e.g. *gljiva – šljiva* 'mushroom' – 'plum') was administrated.

b. Phonological analysis and synthesis was tested, as well. A child was asked to build a word from offered letters and to identify the new word obtained by deletion of a letter in a word (e.g. *plot* → *pot*).

c. In the Rapid naming (RAN) test a child was asked to name pictures as quickly as possible in a minute. The pictures contained objects that are familiar to children: toys, pets, fruits, etc. *d.* Phonological memory was tested by saying a word to a child and asking him to repeat it letter by letter. The task was performed forward and backward (e.g. *mačka* 'cat': *m-a-č-k-a* and *a-k-č-a-m*).

e. Phonological tests include three repetition tests, as well: Repetition of semantically similar words (all words in a list read to the child were semantically similar, for example, they were names for domestic animals); Repetition of phonologically similar words and Repetition of pseudo-words. Pseudo-words were built from frequent Croatian nouns by transposition (e.g. *orem* from *more* 'sea').

Morphology and syntax were tested on five tests (v. Table 3):

a. Noun morphology was tested on a picture task: a child was shown a picture of a, say, king and the child had to fill the sentence offered by the test administrator: "*Here is a*______." Then, an empty screen was shown and the child had to finish the sentence using the correct case (Genitive): *Nema* ***kralja*** '*There is no* ***king***.' Finally, a picture showing three kings was shown and the child had to finish the sentence using the correct number (Plural). The choice of nouns enabled inclusion of all grammatical features regarding case and number, for example, long and short Plural, moving *a* or palatalization.

*b.*Verbal morphology was tested on a Prefixation test on which a child had to put a prefix on a verb in order to express the perfective meaning required by the picture (e.g. *Dječak jede kolač. Na kraju je dječak kolač* ***pojeo.*** *'The boy is eating the cake'. Finally, the boy* ***has eaten*** *the cake.'*).

c. Prepositions were also tested on a picture task: two objects were shown in various spatial relations. The child either had to show the object *behind* another object (comprehension) or to say which object was where (production).

d. Possessive relations were tested by showing a picture to a child and saying who has the object depicted on it (me, he, grandmother, etc.). The child was then asked to whom the object belonged (eliciting thus possessive adjective or pronoun).

e. Finally, Sentence repetition task was performed using ten sentences of increasing syntactic complexity (verb + increasing number of arguments, more and more complex noun phrases: from single nouns, Adj+N constructions, Dem+Adj+N constructions…).

Lexicon and semantics was tested on three tests:

a. Peabody Picture Vocabulary Test (comprehension) and a lexical production test (object naming).

b. In addition, Homonyms, synonyms and antonyms were tested in a test in which a child was ask to say “the other word for_____”, “the opposite of______” or “what else ______ meant”.

c. Categorization was tested on a picture task in which a child was asked to group similar pictures together (e.g. fruit vs. trees or domestic vs. wild animals).

d. Finally, narrative abilities were assessed using The Bus Story (Renfrew, 1969).

Two non-verbal IQ tests were performed on each child – WISC Wechsler Intelligence Scale, i.e. one of its subtests, the Block Design Test, (Wechsler, 1974) and Raven Progressive Matrices (Raven et al., 1998). The two tests were crucial for the inclusion of the SLI children into the study: the children were included into the study if the results on the language tests were low and the score on the IQ tests was at least 85, i.e. if the results on the language tests were low on at least one language component, and the non-verbal IQ quotient was at least 85, the child was included into the study as a child with SLI (two participants actually scored 85). The highest IQ score was 112; therefore, the IQ range was 85-112.

4.5. Procedure

a. Reaction time was measured with the E-prime Response Box with the participant sitting in a chair in front of a computer screen. For each experiment *(‘case’, ‘tense’, ‘gender’ and ‘quantifier’*) 20 stimuli per condition were used (sentences or word pairs).

The participant had to press one of the two buttons of the Response Box, one for each experimental condition (violation and non-violation) as soon as he/she decided whether the target word (the last word in a sentence, the second word in word pair experiments) was correct or not. The data were collected on a recording computer in a format suitable for statistical analysis.

b. The behavioral measures (verbal and non-verbal abilities) were tested in the Clinical Research Unit. Each child was tested by a language and speech pathologist and a psychologist who administrated the WISC and Raven Progressive Matrices Test. The testing was completed in two sessions (i.e. verbal and non-verbal abilities were measured separately) due to fatigue and loss of concentration inevitable when the tests took more than 45 minues. A child and the test administrator were alone in the room, but the one-way mirror allowed for monitoring the test procedure.

All ERP recordings were performed in the Laboratory for Psycholinguistic Research, University of Zagreb. The recordings were performed in a darkened room with the participants sitting in an armchair in front of the computer screen. All recordings were performed on a 40 channel NeuroScan NuAmps amplifier. The system consists of the amplifier, Stim II device for precise presentation of the stimuli (with 1 ms precision), stimulus computer and a recording computer with software for on-line and off-line analysis (Acquire and Edit, respectively). NeuroScan QuickCaps with 30 Ag/AgCl recording electrodes, 4 ocular (HEOL, HEOR, VEOU, VEOL) and 2 mastoid electrodes (M1 and M2) were used in all recordings. For statistical analysis SPSS 13.0 (2004) software was used. The caps employed standard electrode mounting based on 10-20 system. Recordings were referential and an average reference was used as suggested by, for example, Picton et al. (2000).

Continuous EEG signal was recorded from each participant. The A/D conversion rate was set on 1000 Hz with the resolution of 22 bits (maximal values for the equipment). Notch filter was used (50 Hz). High pass filter was set on 0.1 Hz with 6 dB/octave slope (minimal values) while the low pass filter was usually set on 70 Hz. However, sometimes this value was lowered down to 50 Hz to account for the electromagnetic noise. The slope also varied from 6 dB/octave to 12 Db/octave, depending on the recording conditions in that moment. NeuroScan eye-blink reducing software based on linear derivation was used to reduce eye-blinks. Movement artifacts or parts of the recordings too contaminated with noise were rejected in order to obtain a clear data set.

The continuous EEG signal was epoched off-line. The epoched interval was -100 to 1000 ms around the trigger. The epoched signal was then averaged. After averaging, baseline correction was performed with the pre-stimulus interval taken as the baseline. Finally, a smoothing function (available in the Edit software) was applied if necessary, depending on the high frequency noise still present in the average.

5. RESULTS AND DISCUSSION

5.1. Adults

5.1.1. Behavioral results

In ‘case’, ‘tense’, ‘gender’ and ‘quantifier’ experiment behavioral results (i.e. reaction time measurements) were done separately, on an e-prime equipment and software. The results are shown on Figures 13 and 14.

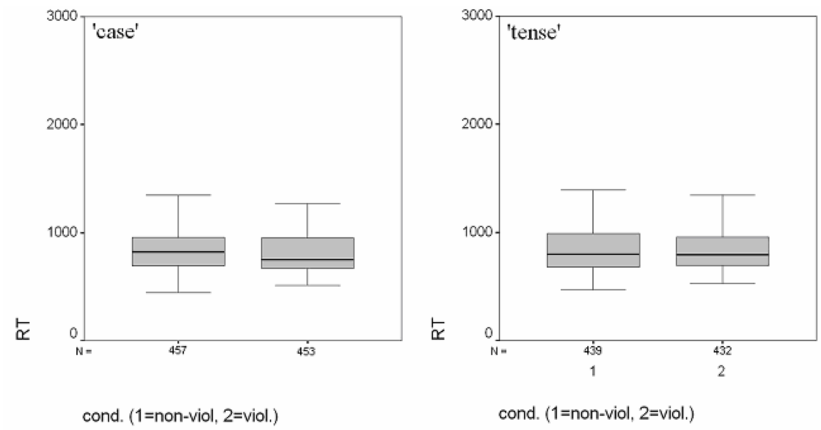

Figure 13. RT results for ‘*case*’ and ‘*tense*’ experiments

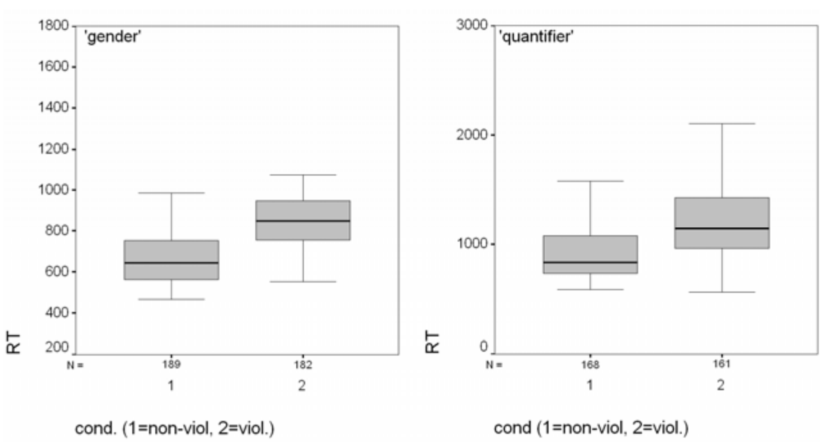

Figure 14. RT results for ‘*gender*’ and ‘*quantifier*’ experiments

As clearly visible from the box plots on Figure 13, no difference was obtained between ‘*case*’ and ‘*tense*’ experiments and between the conditions within each experiment.

Figure 14 reveals that the participants were slower in the second experiment and that the dispersion of responses was bigger. Numerical results are given in the Table 4.

Table 4. Behavioral results (RT-measurements) for the first group of experiments

Experiment	N	Mean RT	Mean RT non-viol. Cond.	Mean RT Viol. Con.	Paired t-test	Sig.
'case'	23	843,5 ms	842 ms	844 ms	0,017	p=0,987
'tense'	23	883 ms	871,8 ms	896,6 ms	0,635	p=0,527
'gender'	10	774,7 ms	693,6 ms	858,7 ms	4,428	p<0,001*
'quantifier'	10	1095,3 ms	955,5 ms	1280,6 ms	4,131	p<0,001*

*Statistical significance at the p<0,001 level.

The statistically significant difference between the experimental conditions was found in the '*gender*' and '*quantifier*' experiment (marked with a star) using a paired t-test. The percentage of correct responses was very high: 99% in 'case' and 95% in 'tense' experiments. Error rates were higher in the auxiliary experiments; while there were 93% of correct responses in the '*gender*' experiment, the percentage of correct responses was lower in the '*quantifier*' experiment, it was 83%. In addition, some participants reported that they found the '*quantifier*' experiment somehow 'more difficult' than '*gender*' experiment.

The profound difference found only between '*gender*' and '*quantifier*' experiment can be attributed to the categorization in terms of semantics or lexical subcategory. In fact, if we put the linguistic theory aside for a moment, all other experiments, '*case*', '*tense*' and '*gender*', can be understood as purely 'grammatical' with some sort of agreement error, be it a case, tense or gender error. The fact that this kind of error does not exist in the '*quantifier*' experiment, but that the error is on a different level, might explain the difference in the reaction times. However, these results are inconclusive. It might be that the processes underlying comprehension in the '*case*' and '*tense*' experiments cannot be characterized in terms of 'less difficult' or 'more difficult', as '*gender*' and '*quantifier*' experiments were characterized, but that the underlying processes are still different. After all, RT is not the best choice of a method if the processes to be measured are not additive. Therefore, the application of the ERP showed justified.

5.1.2. Electrophysiological results

In each experiment grand averages were obtained using NeuroScan Edit software and the data were tested for statistical significance between the experimental conditions using ANOVA.

'Case' experiment. The overall results of the '*case*' experiment for 23 adult participants are presented on Figure 15.

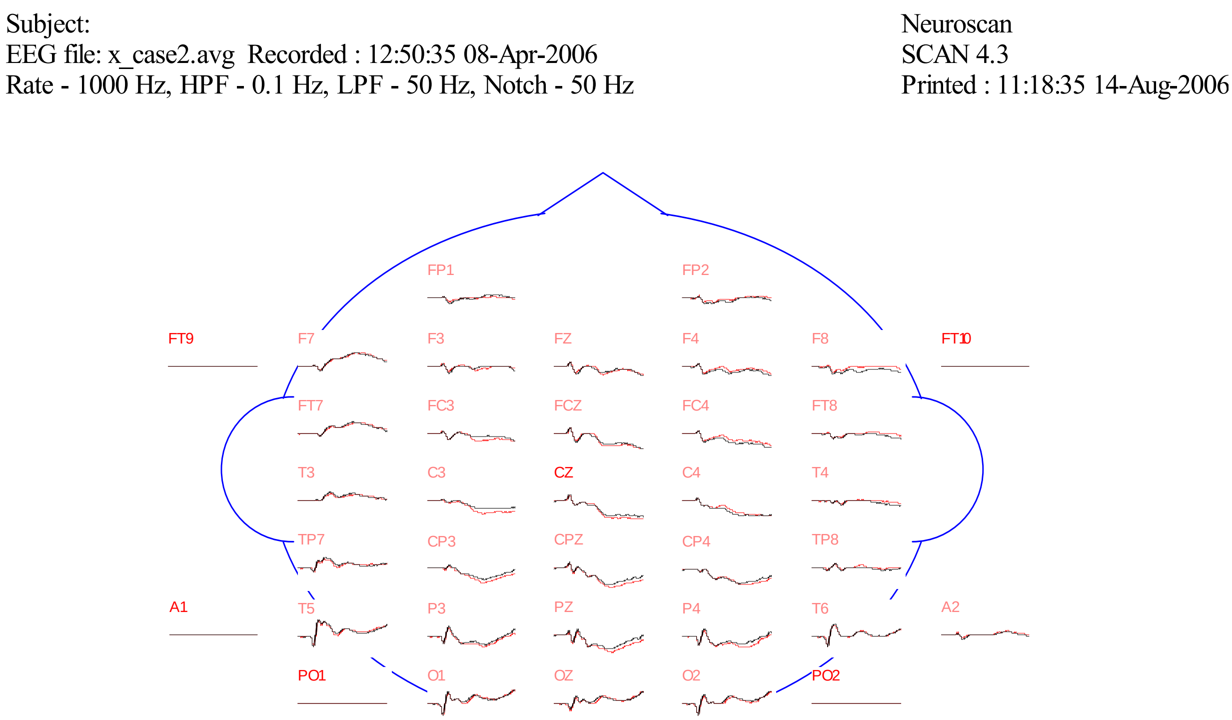

Figure 15. An overview of the results in the '*case*' experiment (violation = red)

A small negative deflection on the left frontal electrodes (F3, FC3) followed by a slow positive wave over the central and parietal electrodes can be seen. The negative wave on the frontal electrodes with the left hemisphere maximum can be better seen on Figure 16, over the F3 and Fz electrodes. The left frontal distribution and the latency correspond to the Left Anterior Negativity (LAN) component (Münte et al., 1993, Osterhout & Holcomb, 1992) The peak was measured with the NeuroScan peak detection algorithm (part of Edit off-line analysis toolkit) and had a latency of 327 ms.

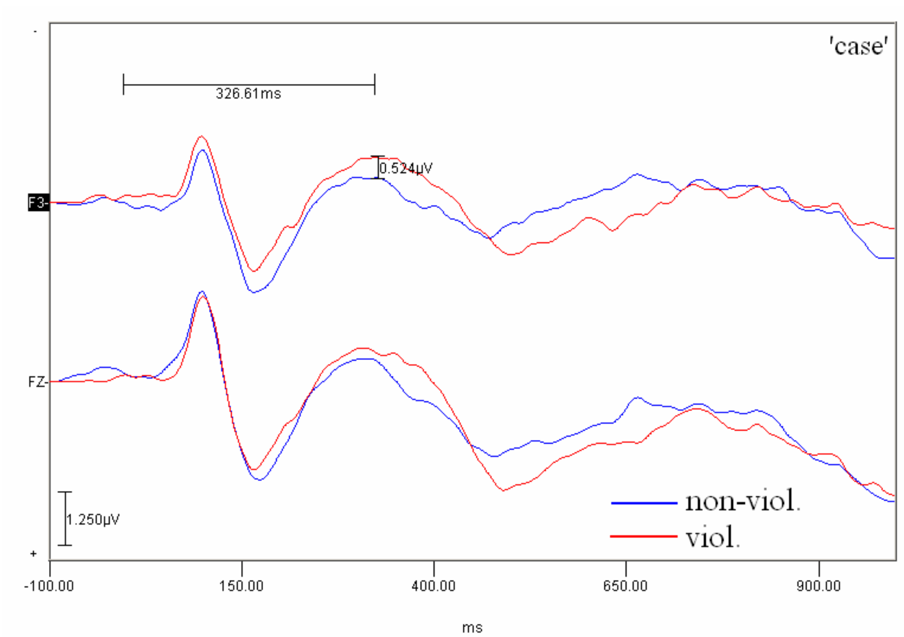

Figure 16. LAN effect in the '*case*' experiment (F3 and Fz electrodes)

Statistical significance was tested in the 220 – 420 ms interval. Table 5 shows the statistically significant results obtained at the left frontal electrode sites. The results for all electrodes are given in the Appendix.

Table 5. Statistical significance of the LAN effect in the '*case*' experiment

Electrode	F(1,336)	p
f7	10,896	,001*
f3	218,522	,000*
fz	39,929	,000*
ft7	68,423	,000*
fc3	16,162	,000*
fcz	30,455	,000*

*Statistical significance at the p<0,001 level.

The LAN component was followed by the broad positive wave with the peak at around 600 ms. It can be identified as the P600 (Coulson et al., 1998). Both LAN and P600 were recorded on the Cz electrode (Figure 16). The P600 effect was prominent over the parietal electrodes, especially on Pz electrode (Figure 17). The peak latency was 602 ms.

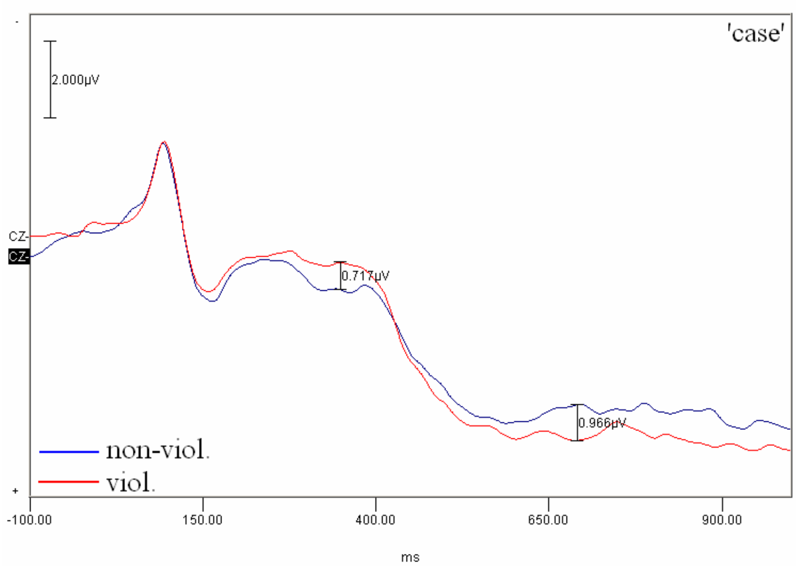

Figure 17. LAN effect and the late positivity at the Cz electrode

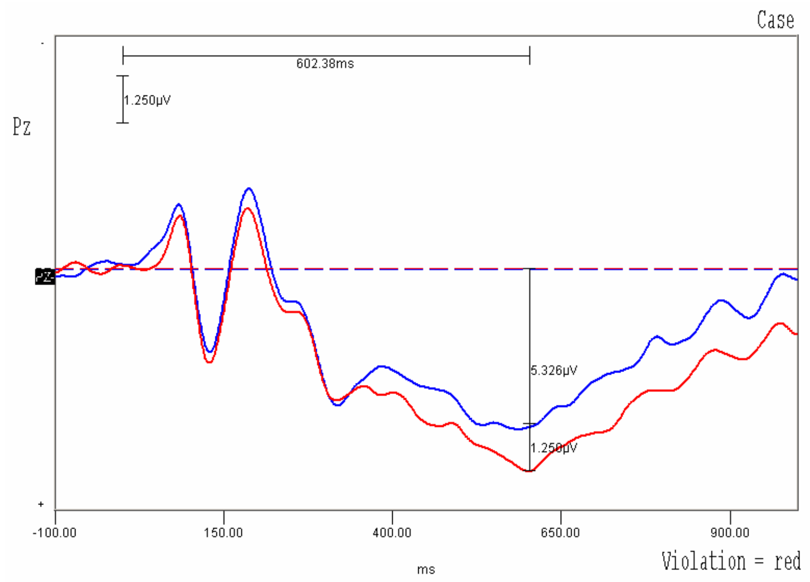

Figure 18. The P600 in the '*case*' experiment measured on the Pz electrode

The P600 component was tested statistically in the in 560 – 660 ms interval. The results obtained at the centro-parietal electrodes are given in the Table 6. The results for all electrode sites are given in the Appendix.

Table 6. Statistical significance of the P600 effect in the *'case'* experiment

Electrode	F(1,196)	p
Cp3	2351,678	,000*
Cpz	991,114	,000*
Cp4	60,164	,000*
Tp8	192,859	,000*
T5	229,039	,000*
P3	604,203	,000*
Pz	983,335	,000*
P4	1577,015	,000*
T6	,541	,463

*Statistical significance at the p<0,001 level.

In order to confirm the identification of the ERP components scalp distribution map is given on Figure 19. The map represents the difference between the conditions and it is calculated by subtracting the non-condition from the condition image thus keeping the polarity of the result unchanged.

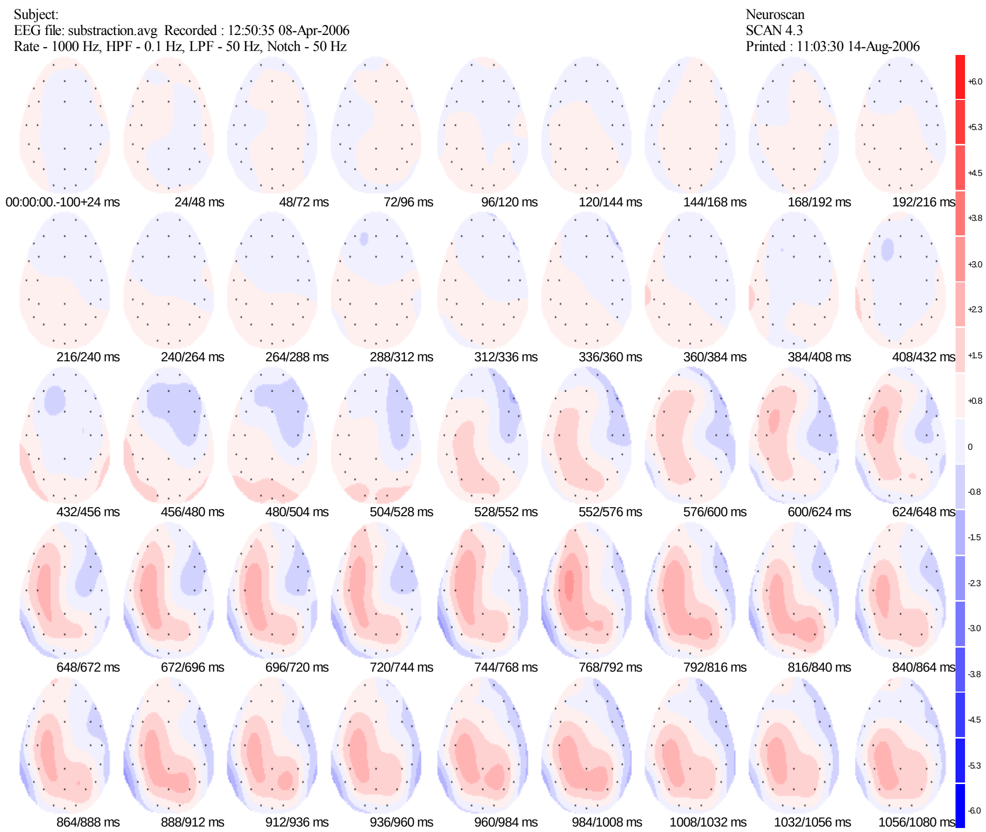

Figure 19. The difference between the conditions in the '*case*' experiment

The scalp distribution images show the negative wave starting around 400 ms at the left anterior electrode sites and lasting to around 500 ms at the anterior electrode sites. It is followed by a positive wave over central and parietal regions starting at around 550 ms and lasting till the end of the epoch (1000 ms). This distribution with parietal maximum is typical for P600 or '*syntax positive shift*' (SPS) (Hagoort et al., 2000). However, as they report:

> P600/SPS has a fairly equal scalp distribution, whereas the second phase (750-100 ms) shows a clear parietal maximum (p. 293).

In the same paragraph Hagoort et al. make difference between syntactic preferences and syntactic violations claiming that the violations elicit more posterior while syntactic preferences elicit more frontal distribution. The P600 elicited in the '*case*' experiment shows both frontal and parietal distribution at different latencies. The frontal distribution shows clear left hemisphere maximum while the second part shows central distribution. While case violation can be easily related to the posterior part of the P600, in this experiment there is no difference in preferences between the conditions. Therefore, the two phases in the P600 component could be interpreted in terms of violation only: constituent error, i.e. argument structure error detection, macrorole violation, i.e. syntax-to-semantics mapping and integration and repair. In such interpretation constituent structure error detection can be related to LAN, macrorole violation with the left anterior portion of P600 while repair and integration processes can be related to the second phase of the P600 component. This is, in a way, in accordance with Bornkessel & Schlesewsky (in press) in which they report an 'early positivity' and 'P345' for macrorole violation in German, Dutch and English (for example, in the German verb final sentences with object in the Dative as in *…dass der Dirigent den Sängerinnen <u>aufällt</u>*. The verb requires the Undergoer macrorole for the noun in Nominative and the initial macrorole assignment based on the Nom.–Dat., i.e. marked word order – Actor - should be changed, thus the increased processing costs occur). The difference in latency between the German examples and the results in the present study can be attributed to the difference in the availability of the macrorole information; while in the German example the noun in Dative precedes the verb, in the present study the noun in the Dative was the very last word in the sentence. In the other words, in the German examples macroroles are already assigned when the verb is presented and it is actually the verb that calls for the macrorole reassignment. The same principle is applied in the Dutch experiment, as well. In this study it is the other way around. The Undergoer macrorole cannot be assigned until the last word in the sentence and until the argument structure violation is not detected, the macrorole information is not available, i.e. it is processed later.

The 'tense' experiment. This experiment contained a violation in tense; a different, but still a grammatical violation. The overall results are shown on Figure 20.

Subject:
EEG file: x_tense1.avg Recorded : 13:21:55 08-Apr-2006
Rate - 1000 Hz, HPF - 0.1 Hz, LPF - 50 Hz, Notch - 50 Hz

Neuroscan
SCAN 4.3
Printed : 10:44:12 14-Aug-2006

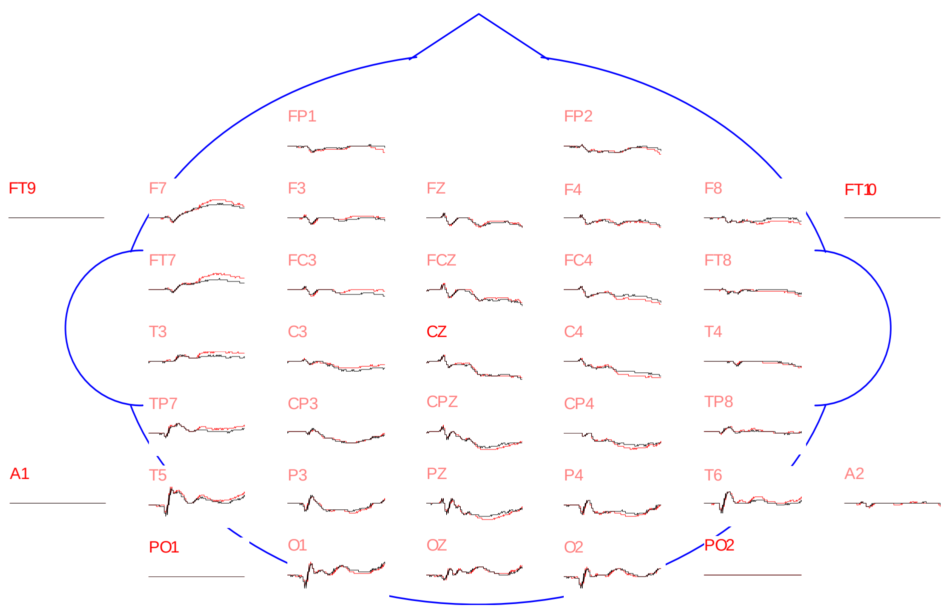

Figure 20. An overview of the results in the '*tense*' experiment (violation= red)

Three features require further attention: absence of LAN, late negative deflection on the left anterior electrodes and P600 with the broad central and parietal distribution.

In difference to the '*case*' experiment, there is no difference in the negative deflection between the conditions in the '*tense*' experiment on the left frontal electrodes in the 300 – 500 ms interval. This can be related to the absence of any structural violation in the stimulus sentences – no argument structure violation and no thematic role violation. However, since there is a violation on the main verb (it is in the wrong form), the integration costs of the sentences in the violation condition are higher, therefore, the P600 effect is obtained. A strong negative deflection is recorded on the left frontal electrodes (F7, F3, FT7, FC3, T3, C3). This negative deflection starts late, at 500 ms, reaches maximum at 650 ms (at F7) and lasts till the end of the epoch (Figure 21). Figure 22 shows P600 on the Pz electrode.

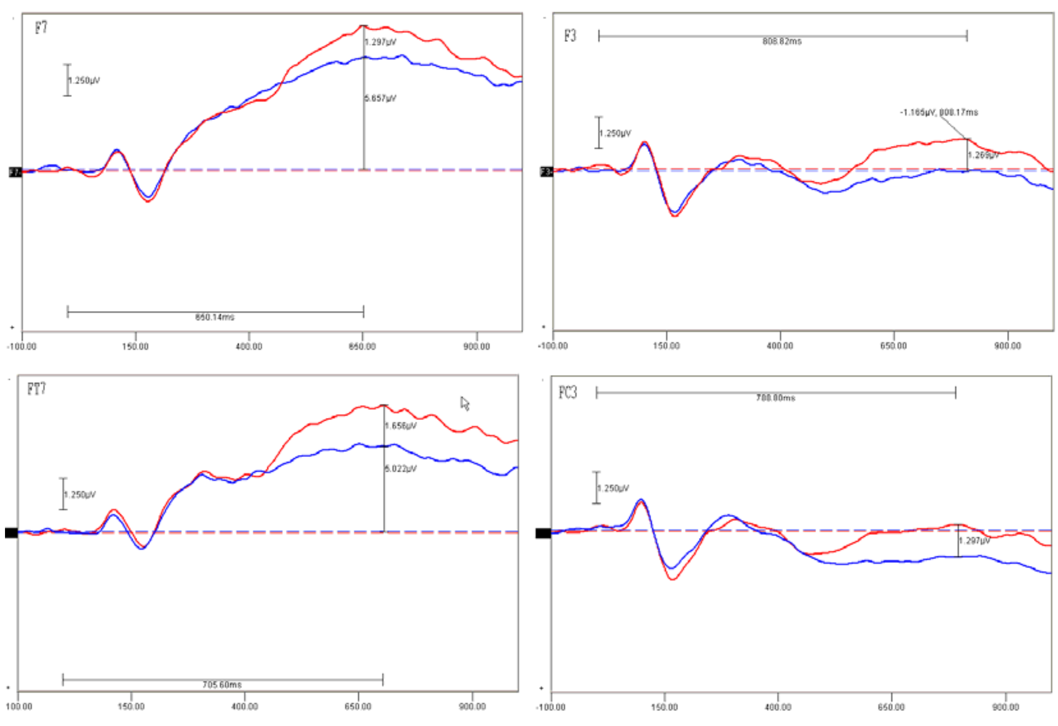

Figure 21. Average waveform for F7, F3, FT7, FC3 electrodes in the '*tense*' experiment

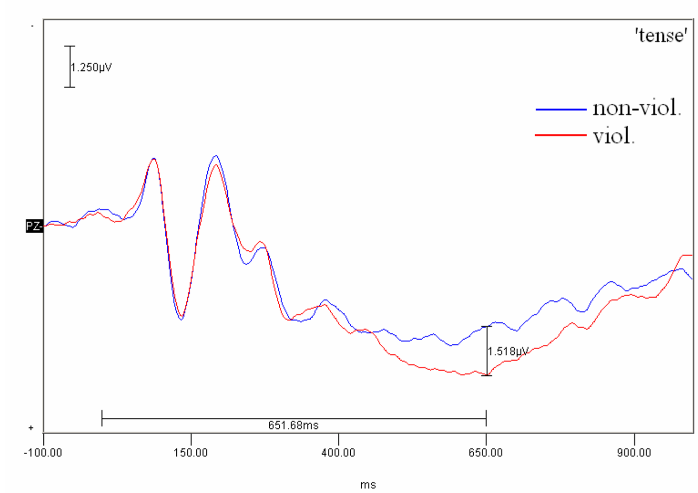

Figure 22. Average waveform for Pz electrode in the '*tense*' experiment

Figure 23 shows distribution maps in the '*tense*' experiment as a difference map between the conditions. The map is obtained by subtracting non-violation condition from the violation condition thus preserving the polarity of the difference.

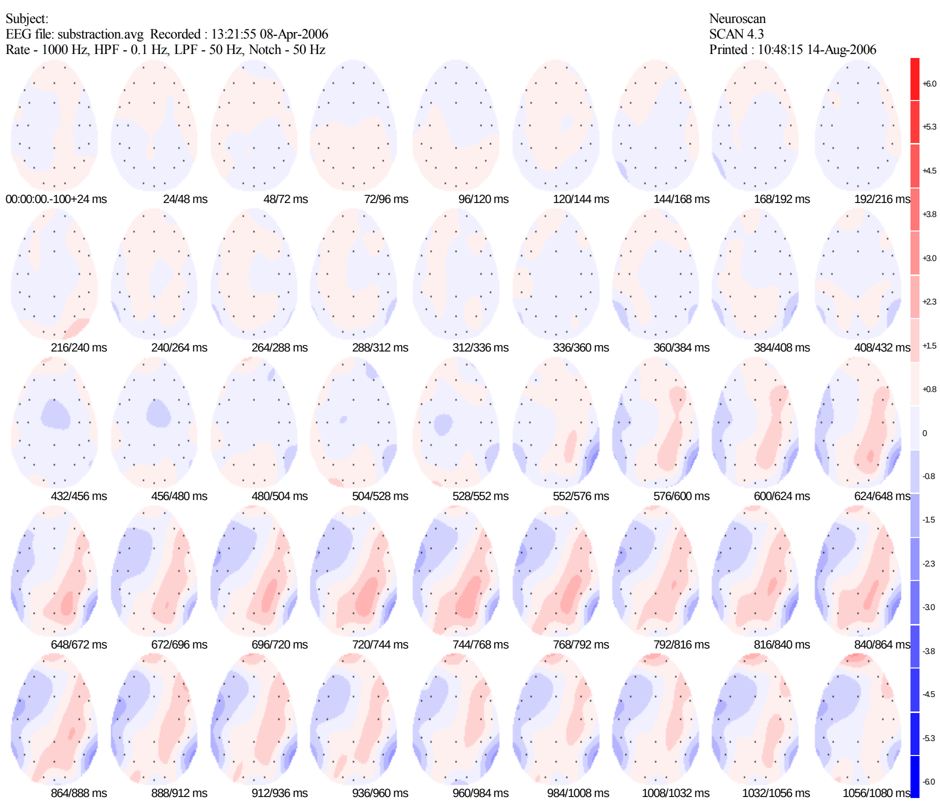

Figure 23. The difference between the conditions in the '*tense*' experiment

The left hemisphere maximum can be seen on Figure 24; it shows the difference between the conditions, left and right view. For comparison, only bottom two rows are shown (i.e. the interval from 650-1000 ms).

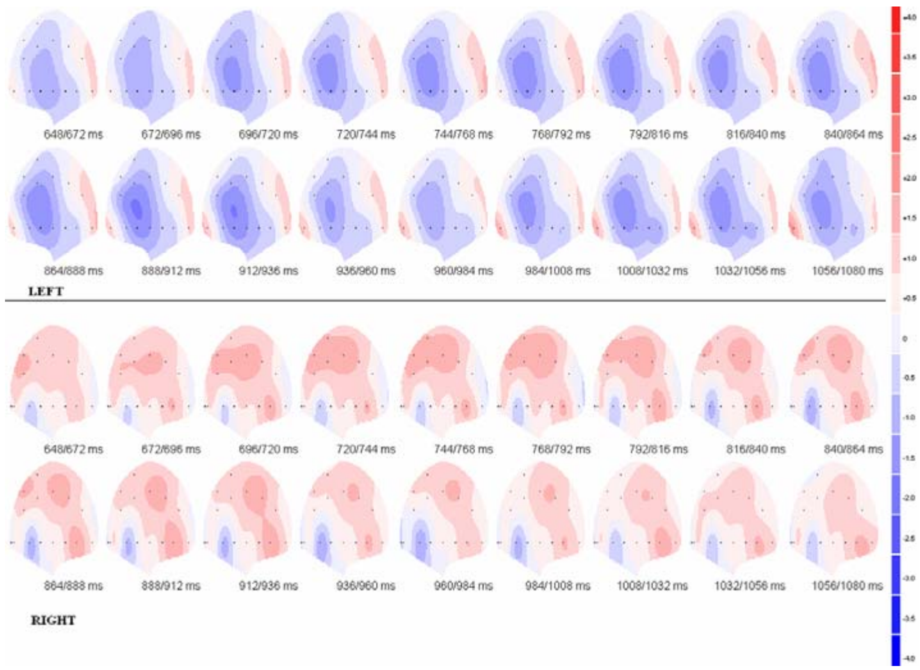

Figure 24. Left and right view (difference map, '*tense*' experiment)

Statistical significance was found on the relevant electrodes, as shown on Table 7. The significance was tested in the 550 - 750 ms interval, i.e. in the interval in which the observed negativity is most prominent.

Table 7. Statistical significance of late negative effect in the '*tense*' experiment

Electrode	F(1,396)	p
F7	2484,126	,000*
F3	96,375	,000*
Fz	532,944	,000*
FT7	5616,576	,000*
FC3	56687,370	,000*
FCz	5033,765	,000*
T3	8824,525	,000*
C3	5833,034	,000*
Cz	98,386	,000*

*Statistical significance at the p<0,001 level.

Table 8 gives the statistical significance of the results obtained in the centro-parietal electrodes in order to establish the significance of the P600 effect.

Table 8. Statistical significance of P600 in the '*tense*' experiment

Electrode	F(1,396)	p
CP3	,341	,560
CPz	1384,720	,000*
CP4	2206,637	,000*
P3	239,674	,000*
Pz	1323,844	,000*
P4	976,651	,000*

*Statistical significance at the p<0,001 level.

While the P600 effect found was expected in the tense violation condition, the late negative deflection at the left frontal electrodes was quite a surprise. Without additional experiments (preferably in other languages, as well) its interpretation must be based on the only manipulation that there is for now: manipulation in the temporal aspect of the sentence meaning. With the auxiliary verb allowing for the unique prediction of the main verb form, the 'location' in time of the action is set. When the violation occurs, it is no longer possible to determine when the action happens. However, no structural violation – in the sense of *who is doing what to whom* – is present, therefore, no LAN, although the violation is, in fact, grammatical. It can, therefore, be argued that this negativity is related to the operator projection of the clause, i.e. to the *tense operator*: it is a grammatical violation, not the semantic one, and it elicits quite a different electrophysiological response from the 'classical' grammatical violations. The obtained negativity could be called N400' (as suggested by Valéria Csépe in a conversation). Full interpretation of the obtained effect will be presented after introducing the results of the two additional experiments.

The 'gender' experiment. Figure 25 shows the overall results for the '*gender*' experiment.

Subject:
EEG file: xrod1.avg Recorded : 16:22:27 09-Jun-2006
Rate - 1000 Hz, HPF - 0.1 Hz, LPF - 50 Hz, Notch - 50 Hz

Neuroscan
SCAN 4.3
Printed : 11:28:21 14-Aug-2006

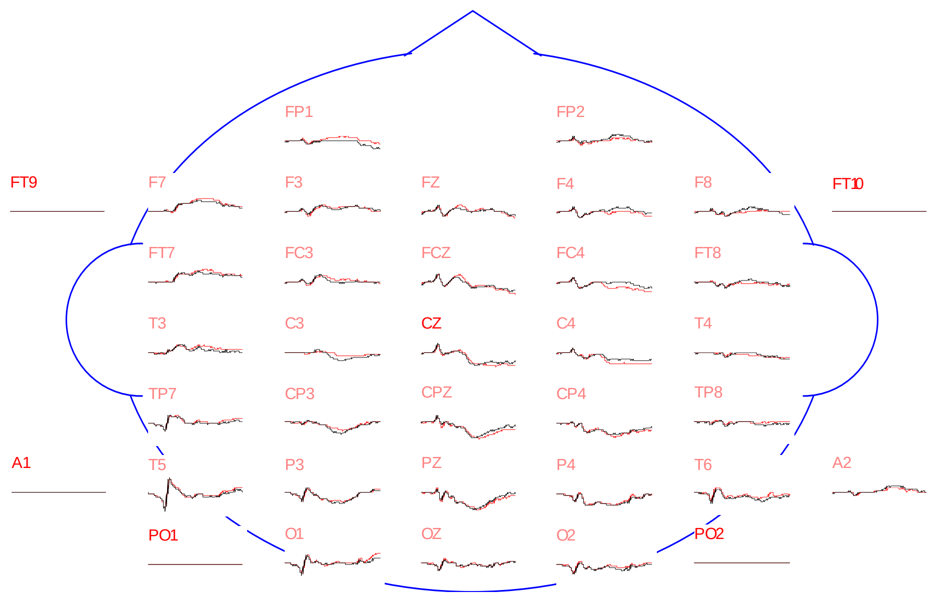

Figure 25. The grand average for the '*gender*' experiment

A negative wave on the left frontal electrodes followed by the positive shift (of more central and parietal distribution) can be observed. Figure 26 shows the negative wave with the peak at 339 ms, i.e. the LAN component obtained in the experiment.

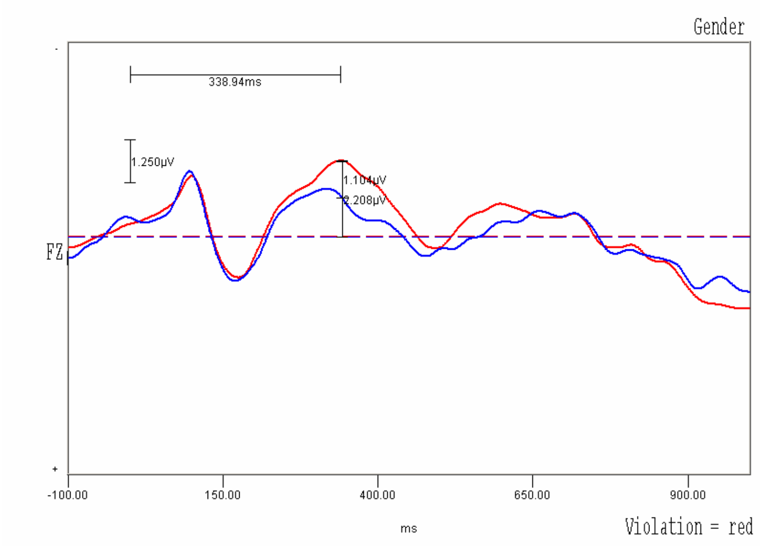

Figure 26. The LAN effect in the '*gender*' experiment

Figure 27 shows the difference between the conditions obtained by subtraction of the non-violation condition from the violation condition thus keeping the polarity of the results.

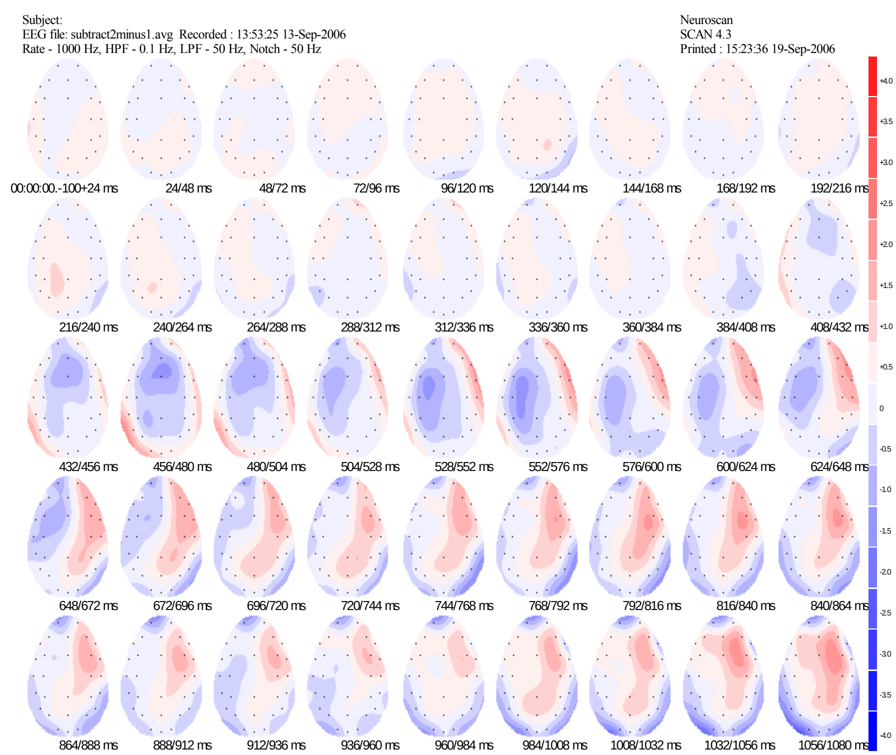

Figure 27. Difference map in the '*gender*' experiment

The distribution maps and the difference map reveal the negative wave with more frontal distribution (LAN) followed by a broad positivity with the biggest difference between the conditions obtained on the right hemisphere electrodes. The results were tested for the statistical significance in the 300-420 ms interval for the LAN effect. The results are given in the Table 9.

Table 9. Statistical significance of LAN in the '*gender*' experiment

Electrode	F(1,236)	p
F7	2,331	,128
F3	26,903	,000**
Fz	274,233	,000**
F4	,207	,649
F8	9,375	,002**
FT7	3,053	,082
FC3	67,781	,000**
FCz	98,290	,000**
FC4	,074	,785
FT8	6,377	,012*

*Statistical significance at the p<0,05 level.
**Statistical significance at the p<0,01 level.

The difference between the experimental conditions is significant on the left anterior electrodes (F3, FC3) and on frontal central electrodes (Fz, FCz). However, no significance was measured on F7 and FT7 electrodes, i.e. the LAN effect obtained in the experiment had left-to-central maximum. Table 10 shows the statistically significant differences between the conditions in the 550-720 ms interval. The P600 effect is visible on the CPz electrode, for example (Figure 28).

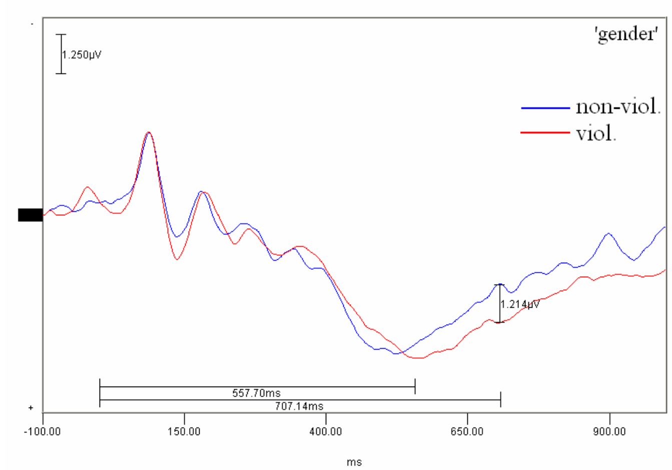

Figure 28. P600 effect on the CPz electrode in the '*gender*' experiment

Table 10. Statistical significance of P600 in the '*gender*' experiment

Electrode	F(1,336)	p
FC4	41003,805	,000**
C4	8479,653	,000**
T4	5,796	,017*
TP7	1281,622	,000**
CP3	41,350	,000**
CPz	213,816	,000**
CP4	192,938	,000**
TP8	87,921	,000**
T5	444,684	,000**
P3	2,479	,116
Pz	42,013	,000**
P4	45,081	,000**

*Statistical significance at the p<0,05 level.
**Statistical significance at the p<0,01 level.

The results show the LAN-P600 effect obtained in numerous experiments with syntactic violations. The P600 effect is small due to the overall simplicity of the stimuli: the integration costs of the word pairs must be smaller than the integration costs related to the whole sentences.

'Quantifier' experiment. The overall results for the '*quantifier*' experiment are given on Figure 29.

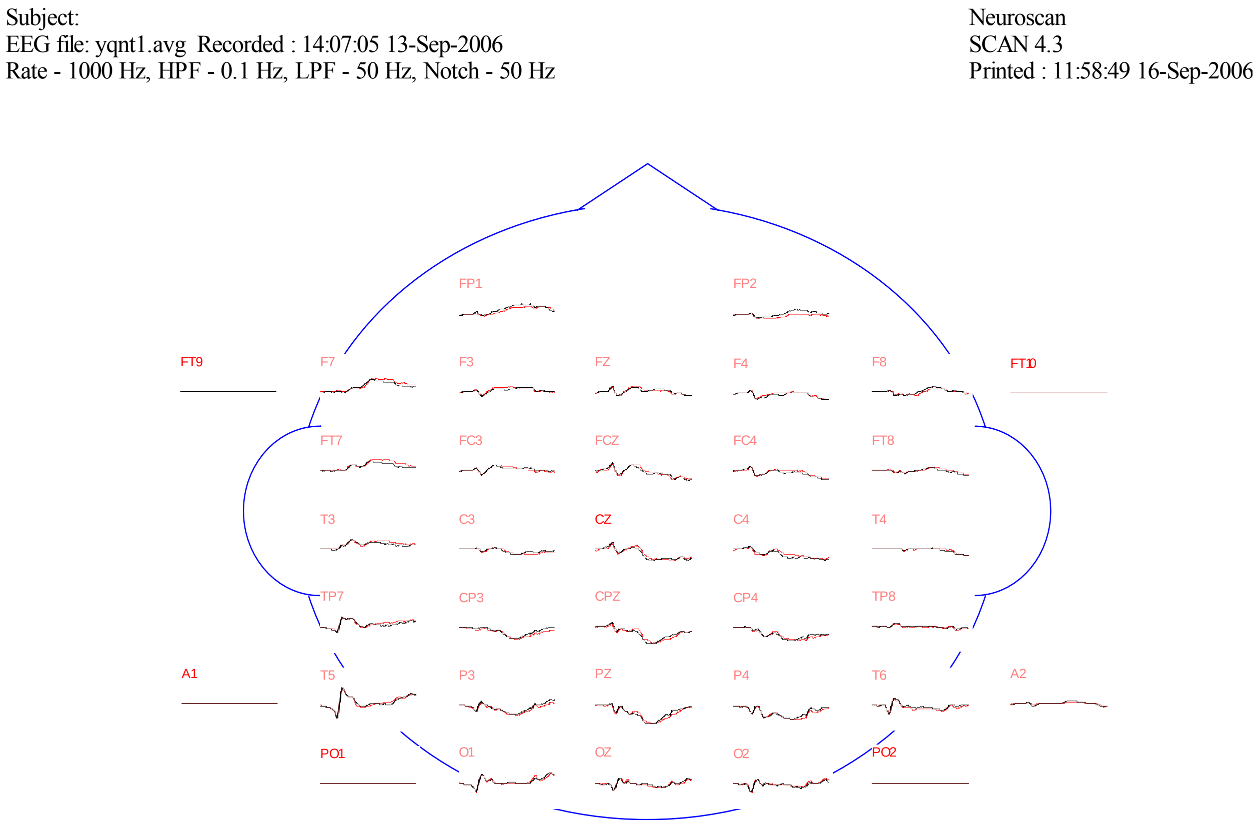

Figure 29. The grand average (all electrodes) for the '*quantifier*' experiment (violation – red)

A closer look reveals negative deflection at the frontal and central electrodes with the stronger effect on the right hemisphere electrodes (Figure 30)

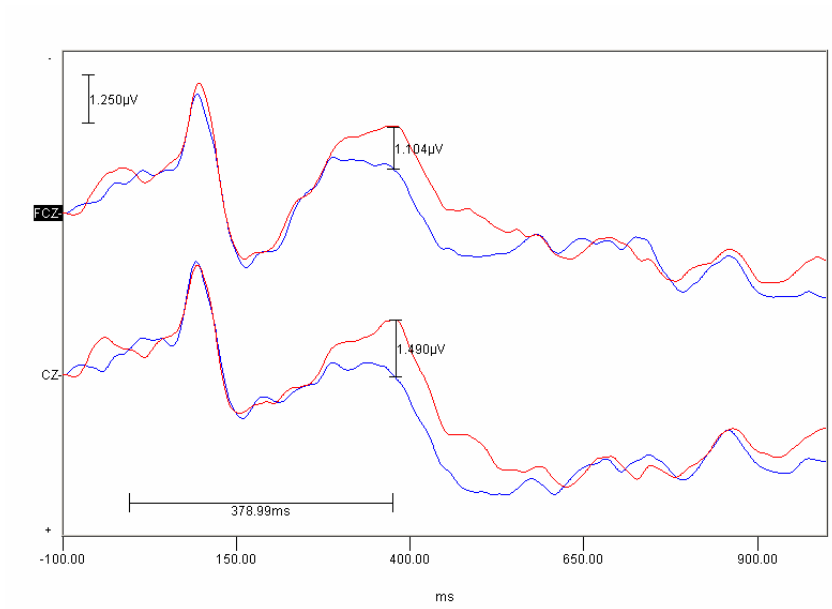

Figure 30. The waveforms at the FCz and Cz electrodes in the '*qnt*' experiment

Scalp distribution for both conditions is given on Figure 31 as a difference between the experimental conditions preserving the polarity of the components.

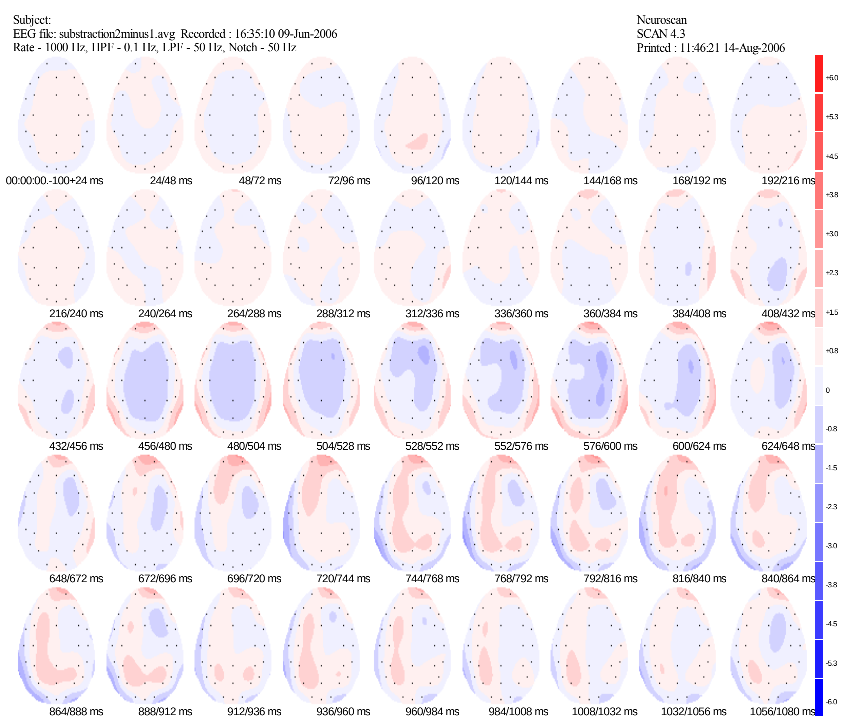

Figure 31. The difference map for the '*quantifier*' experiment

Negative deflection with the maximum over FCz and Cz electrodes and peak latency of 379 ms and broad distribution of this wave over frontal, central and parietal electrodes with right hemisphere maximum indicate the N400 component. This result is partly surprising: the first word in the stimulus – the number – narrows the choice of the second word – the noun – in terms of a grammatical property. The violation in the '*quantifier*' experiment is a word subcategorization error: a subcategorization that divides nouns into countable and mass nouns. But it makes no sense to count uncountable nouns; the resulting phrase has no meaning, hence the N400. Table 11 gives the data on statistical significance of the N400 effect in the 300-500 ms interval.

Table 11. Statistical significance of N400 in the '*quantifier*' experiment

Electrode	F(1, 396)	p
FC3	170,883	,000*
FCz	269,831	,000*
FC4	73,248	,000*
C3	164,745	,000*
Cz	26,272	,000*
C4	74,077	,000*
CP3	22,641	,000*
CPz	63,081	,000*
CP4	73,750	,000*
P3	3,244	,072
Pz	39,746	,000*
P4	49,304	,000*

*Statistical significance at the p<0,01 level.

The N400 obtained in the '*quantifier*' experiment together with the negative deflection (N400') elicited in the '*tense*' experiment allow for some unexpected generalizations and raise some questions about the syntax-to-semantics interface which is the core of sentence comprehension process. The results are compatible with the recent electrophysiological findings in sentence comprehension that make the syntax –

semantics distinction more relative (Kuperberg et al., 2006, Kemmerer et al., in press, Kim & Osterhout, 2005).

There are two points that are common in the two experiments, '*tense*' and '*quantifier*' experiments. First, it is the operator projection that has been manipulated. Second, they elicit a negative deflection, in the '*quantifier*' case a classic N400 and in the '*tense*' experiment some sort of late slow negative wave. The relation between N400 and semantics is widely known whether it is the integration of a word into the sentence context as in Kutas & Hilliard (1980), semantic priming as e.g. in Krehera et al. (2006) or lexical decision task as e.g. in Bentin et al. (1985). In the '*quantifier*' experiment the meaning of the NP cannot be integrated if the preceding number makes no sense with the mass noun, i.e. the quantity of the entity such as water or flower cannot be determined. If we make an analogy (as schematically shown on Figure 32), we can interpret '*tense*' experiment results as a difficulty in the integration of a part of the sentence meaning, i.e. a difficulty in determining the time of the event described in the sentence.

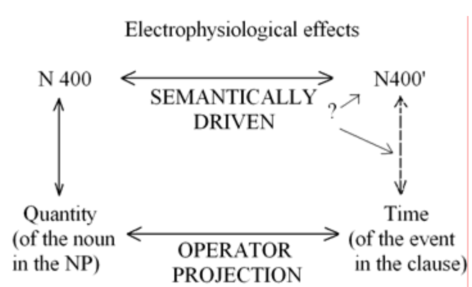

Figure 32. The interpretation of the '*quantifier*' and '*tense*' experiments

This interpretation raises additional questions regarding RRG: if linguistic traits represented on the operator projection elicit semantics-related electrophysiological effects, is there a different syntax-to-semantics linking that maps elements of the operator projection onto some set of semantic properties different from macroroles? In difference to the constituent projection where syntax-to-semantics linking is relatively easy to express as an algorithm, this ‘operators-to-semantics’ linking is more difficult to define. On the one hand there are properties such as tense, aspect, illocutionary force, negation or modality. On the other hand, is there a set of temporal relations and logical operators of negation quantifiers, necessity and possibility, to mention at least some of the elements? Finally, is there a subset that can be applied to all languages and what elements would it include? If RRG is to be followed, only *illocutionary force* is an universal operator. The answer to other questions can be only speculative: if syntax-to-semantics mapping consists of linking the constituents to the arguments of the logical form of a verb defined, basically, as its arguments, this separate linking could, perhaps, be defined in terms of a logical structures as defined in various systems of philosophical logic: for example, *temporal and spatial logic* that captures laws governing temporal or spatial relations between propositions (e.g. UNTIL φψ meaning ‘*at some point later than now φ holds, while at all intermediate points ψ holds*’ (van Benthem, 2002:400)), *modal logic* that captures laws governing the notions of necessity and possibility, or *epistemic logic* that investigates logical behavior of *knowing* or *believing.* While the elements of *temporal and spatial logic* correspond to *tense*, *aspect* or *directionals* as operators in RRG, *evidentials* as RRG operators could be mapped into operators of *epistemic logic.*

To conclude this speculation: when a speaker hears or reads a sentence, its comprehension does not depend only upon the identifying *who is doing what to whom*, but also, *when* the action occurs, *where* or *with whose knowledge*. These information could, in fact, be the focus of the sentence, the very information that is intended to be transmitted. The ERP data in the '*tense*' and '*quantifier*' experiment show that a certain kind of grammatical (syntactic) error – in RRG described on a separate, operator projection, elicits a semantics-like ERP response. This could be interpreted as evidence for mapping between the operator projection and a set of semantic relations as defined in various sorts of modal logic, as suggested above. An augmentation of RRG linking mechanism with a new one, one that links operators and modal logic operators can be suggested, as well – this enterprise would be, however, beyond the scope of this study.

5.2. Children With TLD and Children With SLI

5.2.1. Adult control group

The second group of experiments was meant to provide insight into the developmental aspect of sentence processing by comparing three groups of participants: adults (as a baseline), children with typical language development and children with Specific Language Impairment. All groups of participants took part in the two experiments in which case and tense, i.e. constituent and operator projection were manipulated. The results for the adults are similar to the results in the first two experiments. Figures 33 and 34 show the overview of the results for the '*case-chi*' and '*tense-chi*' experiments obtained in a group of 10 healthy adults.

Subject:
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Neuroscan
SCAN 4.3
Printed : 13:18:15 06-Dec-2006

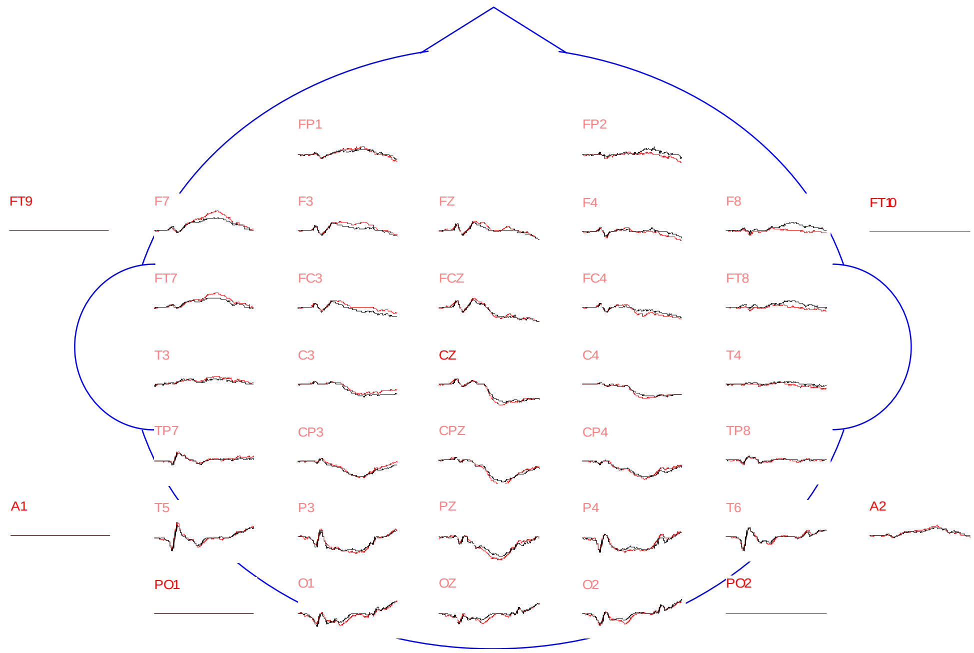

Figure 33. The grand average in the '*case-chi*' experiment – adults

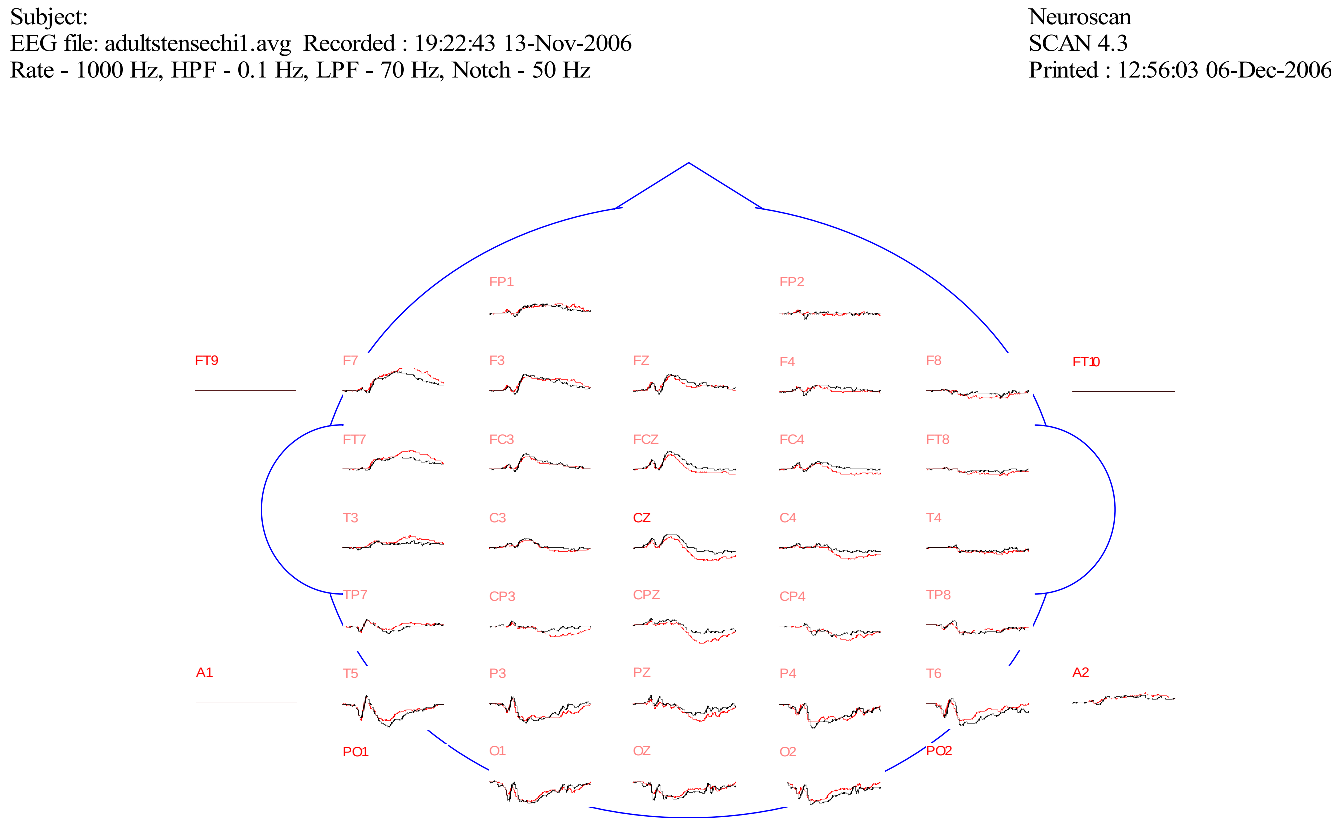

Figure 34. The grand average in the ‘*tense-chi*’ experiment – adults

The results in both experiments are similar to the ‘*case*’ and ‘*tense*’ experiments. A closer look reveals the similarities: Figure 35 and 36 show the LAN-P600 effects in the ‘*case-chi*’ experiment and Figure 37 and 38 show the late negativity at the left frontal electrode sites and P600 effect in the ‘*tense-chi*’ experiment.

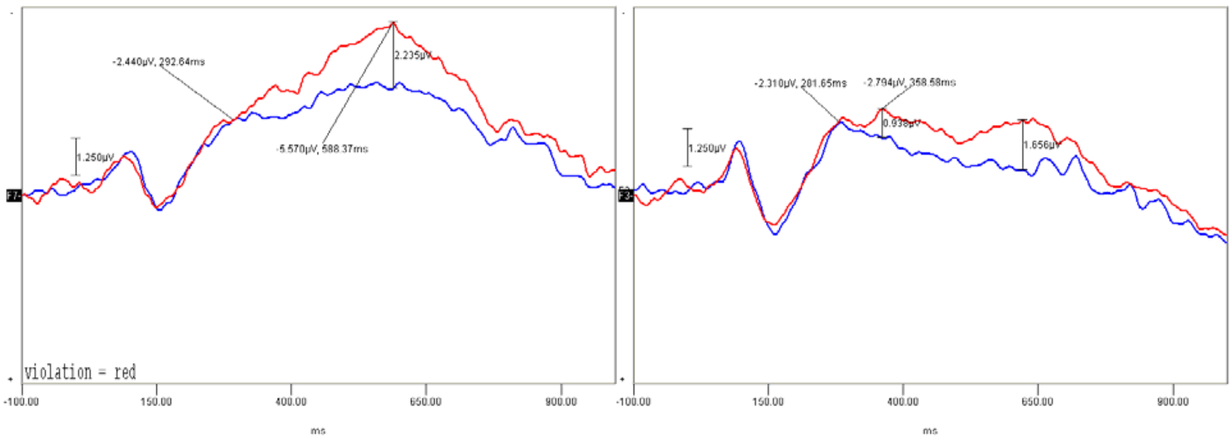

Figure 35. The LAN effect in the ‘*case-chi*’ experiment (F7 and F3 electrodes)

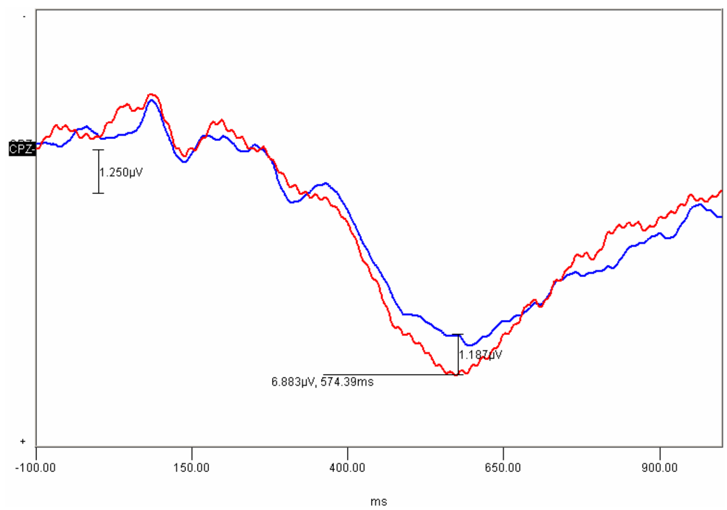

Figure 36. The P600 effect in the ‘*case-chi*’ experiment (CPz)

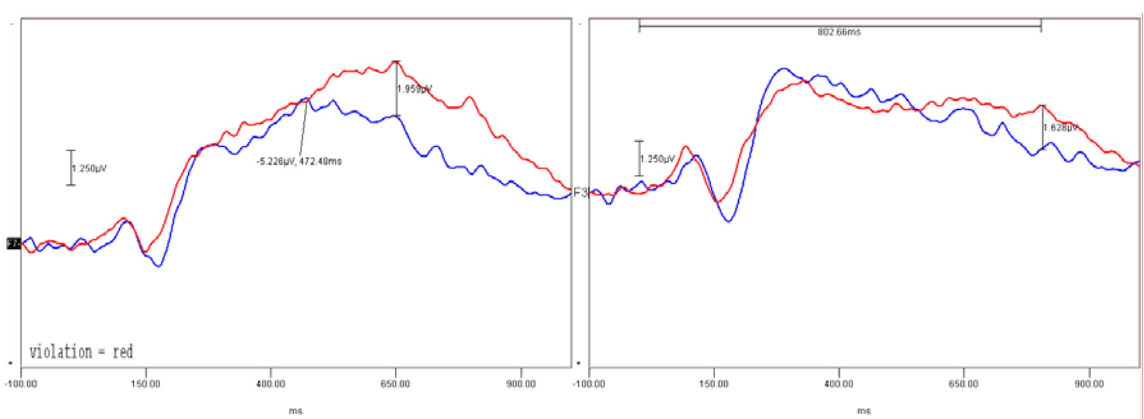

Figure 37. The late negative wave in the ‘*tense-chi*’ experiment

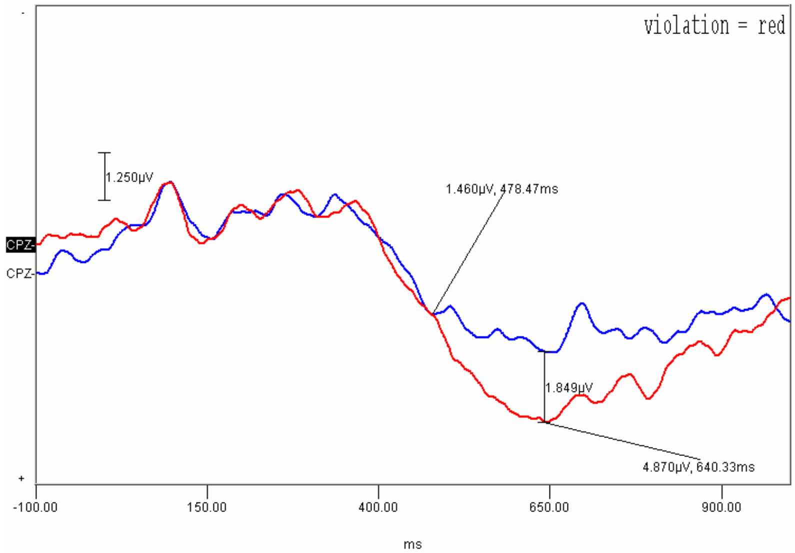

Figure 38. The P600 in the '*tense-chi*' experiment

Distribution maps show the effects clearly. As for other experiments, for brevity only difference maps are given on Figures 39 and 40.

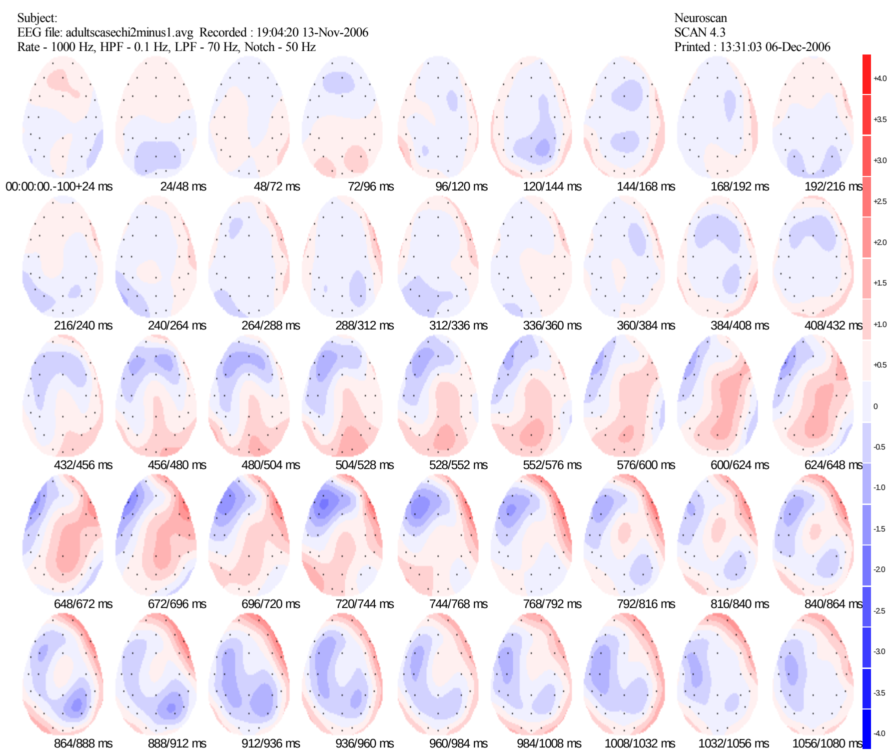

Figure 39. Distribution maps in the '*case-chi*' experiment, difference map, adults

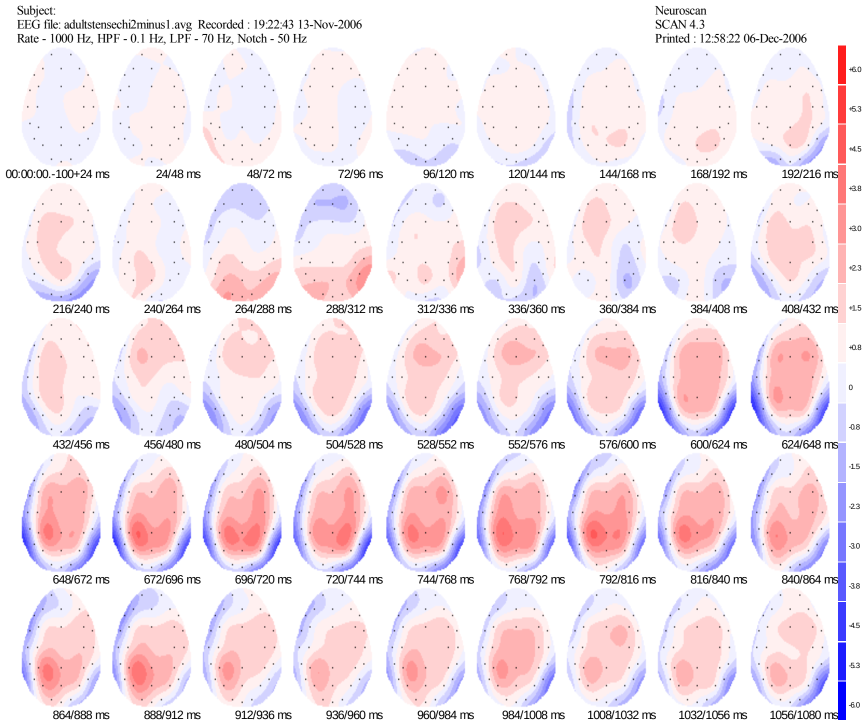

Figure 40. Distribution maps in the '*tense-chi*' experiment, difference map, adults

The late negative wave can be observed in the comparison of the left and right view of the same distribution map as on Figure 41 because it can be observed on the left frontal and parietal electrodes.

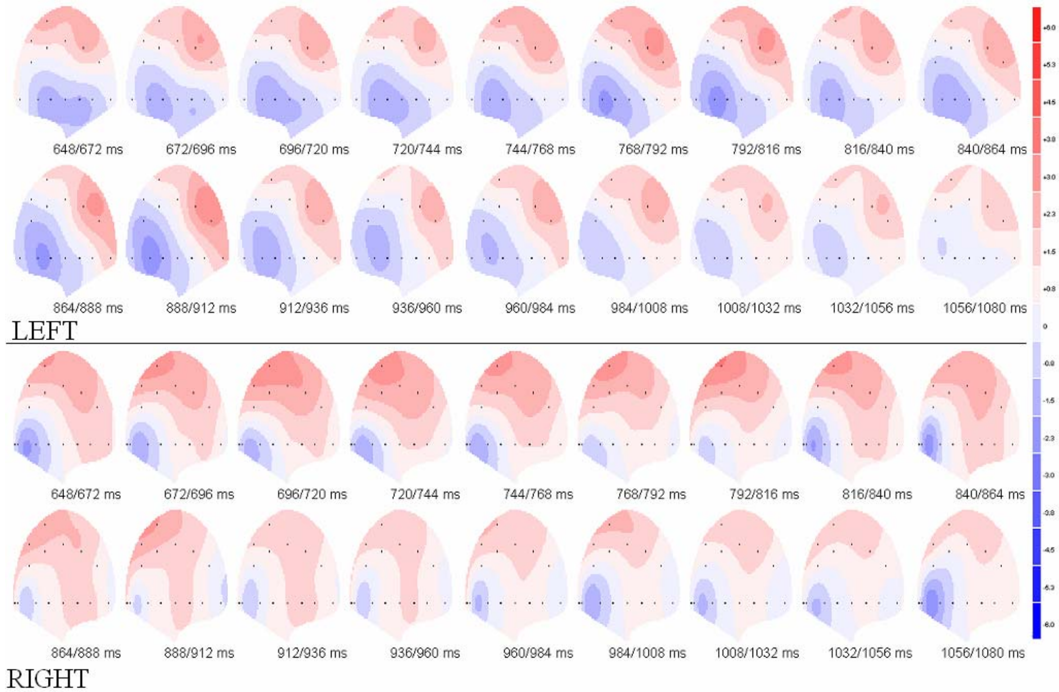

Figure 41. Distribution maps in the '*tense-chi*' experiment, difference map, adults, left vs. right view

Statistically significant difference between the experimental conditions was found for LAN (330-430 ms range) and P600 (550-650 ms range) in the '*case-chi*' experiment, as shown on the Table 12 and 13. Statistically significant difference between the conditions was tested in the '*tense-chi*' experiment. The results for the late negative wave and P600 are shown on Table 14 and 15.

Table 12. Results for ANOVA for the LAN in the '*case-chi*' experiment, adults

Electrode	F(1, 196)	p
F7	2149,048	,000*
F3	1157,255	,000*
Fz	243,051	,000*
FT7	1487,167	,000*
FC3	542,723	,000*
FCz	12,370	,001*

*Statistical significance at the p<0,01 level.

Table 13. Results for ANOVA for P600 in the '*case-chi*' experiment, adults

Electrode	F(1, 196)	p
CP3	,254	,615
CPz	726,307	,000*
CP4	200,195	,000*
TP8	108,606	,000*
T5	202,600	,000*
P3	125,696	,000*
Pz	134,977	,000*
P4	,777	,379
T6	84,524	,000*

*Statistical significance at the p<0,001 level.

Table 14. Results for ANOVA for the late negativity in the '*tense-chi*' experiment, adults

Electrode	F(1, 296)	p
F7	1184,122	,000*
F3	356,377	,000*
Fz	230,432	,000*
FT7	1940,612	,000*
FC3	41,681	,000*
FCz	111,997	,000*

*Statistical significance at the p<0,001 level.

Table 15. Results for ANOVA for P600 in the '*tense-chi*' experiment, adults

Electrode	F(1, 296)	p
C3	61,627	,000*
Cz	18664,845	,000*
C4	3446,318	,000*
CP3	1893,175	,000*
CPz	4939,186	,000*
CP4	989,830	,000*
P3	179,872	,000*
Pz	424,757	,000*
P4	24,789	,000*

*Statistical significance at the p<0,001 level.

The results of the two experiments on the healthy adults resemble the results obtained in the '*case*' and '*tense*' experiments. However, the results contain higher level of noise due to a smaller group of participants. The difference between the first and second group of experiments is more prominent in case of '*tense*' and '*tense-chi*' experiments. It could be attributed to the absence of any temporal adverbs in the '*tense-chi*' experiment (reduced lenght of the stimulus sentences) or to the word order (S-Adv-O-V in the '*tense*' and SVO in the '*tense-chi*' experiment).

5.2.2. Children with TLD

The results obtained in a group of children with typical language are given bellow. Figure 42 show the overall results for the *'case-chi'* experiment.

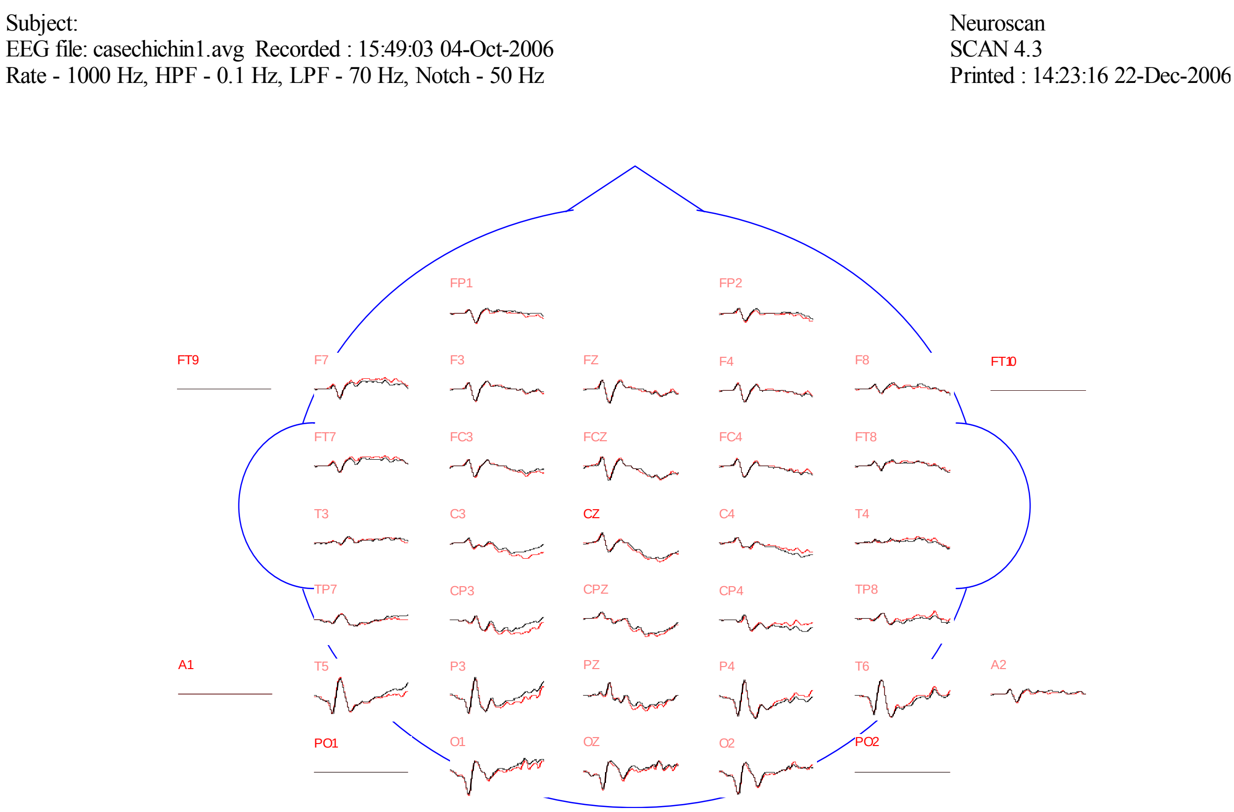

Figure 42. The grand average for TLD children in the *'case-chi'* experiment.

The waveforms reveal the absence of the left anterior negativity (for details, see Figure 43) and a broad positive wave (v. Figure 44).

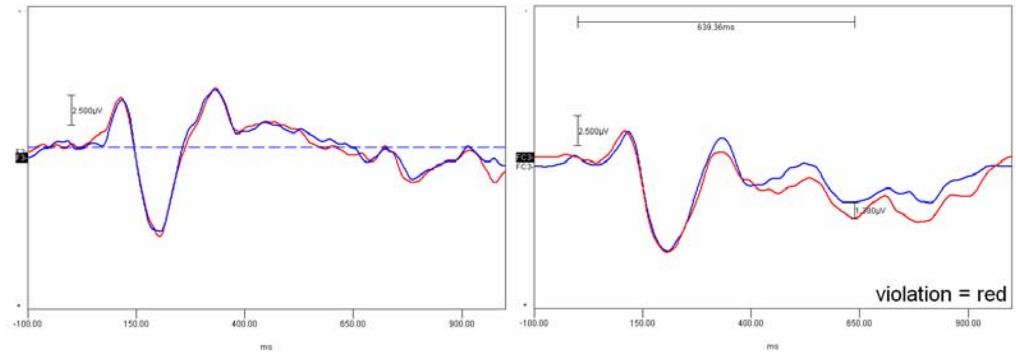

Figure 43. The grand average for the TLD children in the ‘*case-chi*’ experiment-F3 and FCz electrodes

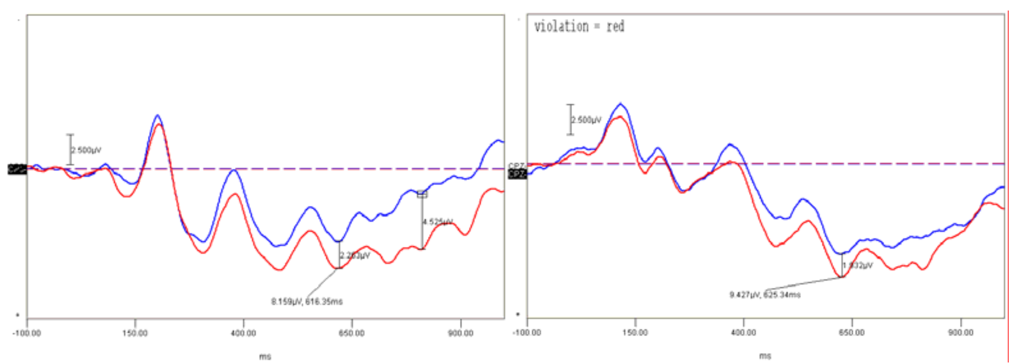

Figure 44. The grand average for the TLD children in the ‘*case-chi*’ experiment-CP3 and CPz electrodes

Statistical data for the F3 and FCz electrodes in the 300 – 500 ms interval are given in Table 16 showing no statistically significant differences between the experimental condition.

Table 16. Statistical data for LAN in the ‘*case-chi*’ experiment in the group of TLD children

Electrode	F(1, 396)	p
f3	,133	,715
fz	2,843	,093

Statistical analysis reveals P600 effect in the 600-700 ms interval for the CP3 and CPz electrodes, as shown on Table 17.

Table 17. Statistical data for P600 in the '*case-chi*' experiment in the group of TLD children

Electrode	F(1, 196)	p
CP3	551,741	,000*
CPz	104,843	,000*

*Statistical significance at the p<0,001 level.

The distribution maps show the positive wave with left hemisphere maximum around 600 ms. Figure45 shows the difference map.

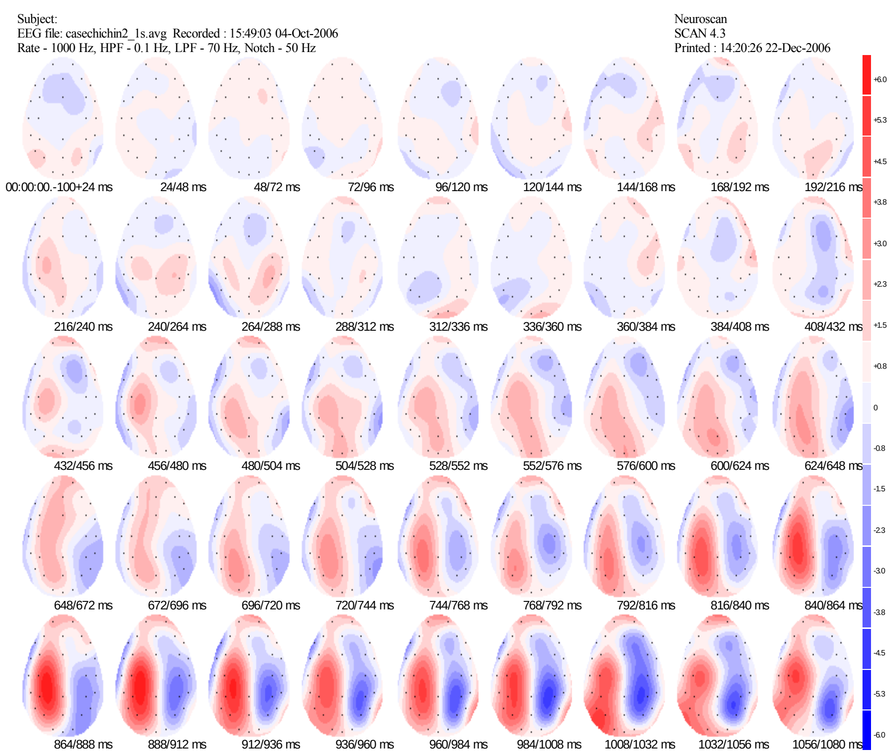

Figure 45. Distribution map for TLD children in '*case-chi*' experiment

The positive and negative deflection (the later shown separately as a waveform in Figure 46) in the 840 – 1000 ms interval can be seen easily. While the positive wave can be identified as P600, the negative deflection could be related to the absence of LAN. However, the interpretation of this negative deflection will be discussed later.

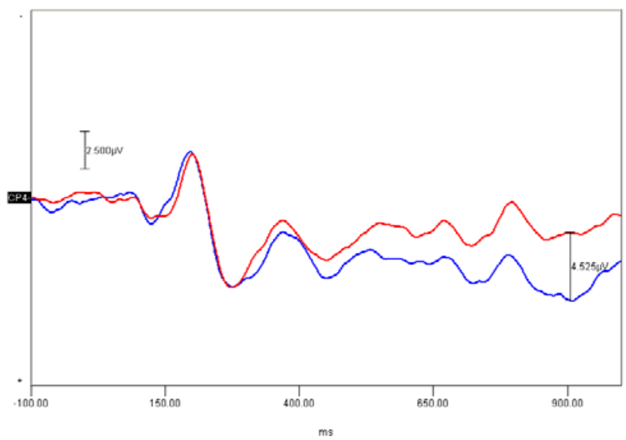

Figure 46. Late right hemisphere negative deflection in the '*case-chi*' experiment, TLD group, CP4 electrode

Figure 47 shows the grand averages for all electrode sites in the '*tense-chi*' experiment in the group of TLD children.

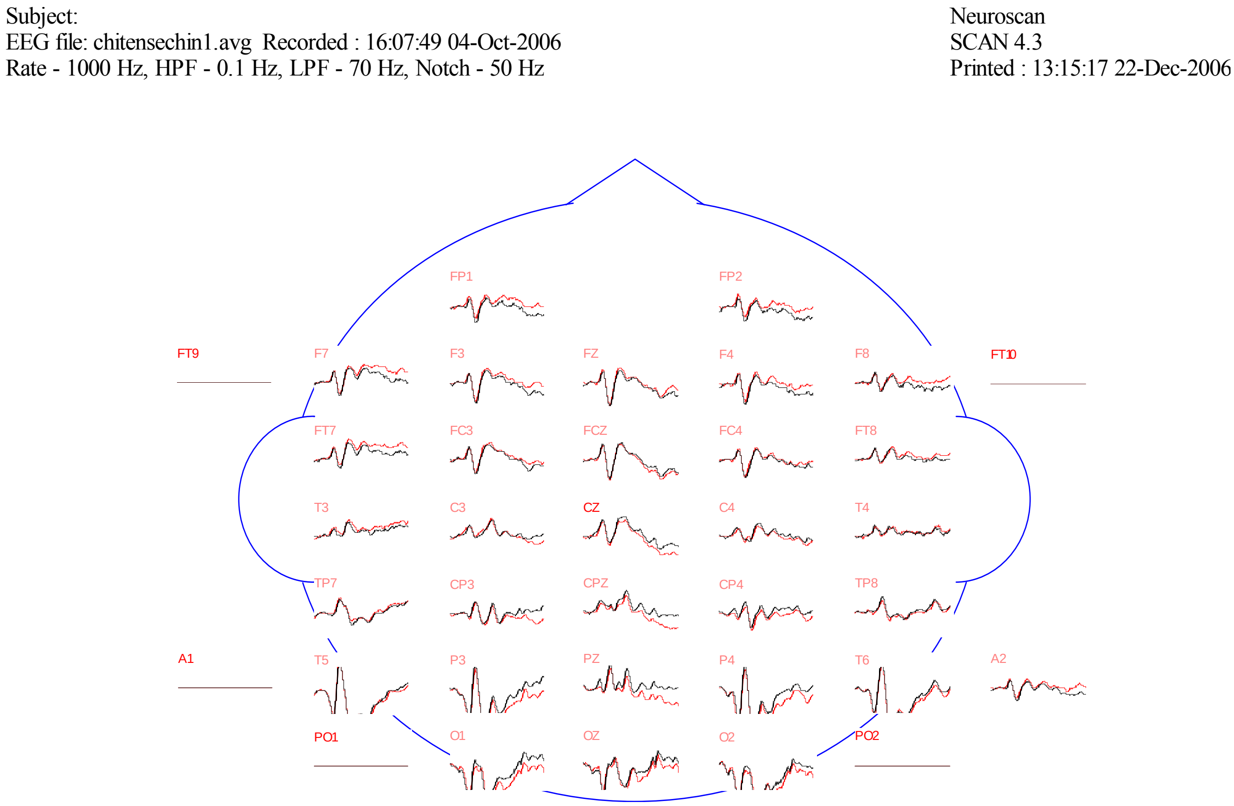

Figure 47. The grand average in the '*tense-chi*' experiment obtained in the group of children with TLD

Apart from P600 effect (Figure 48) the late negativity labeled as N400' can be observed at the frontal electrode sites. However, the negativity has a broader distribution over left and right hemispheres (Figure 49 and 50).

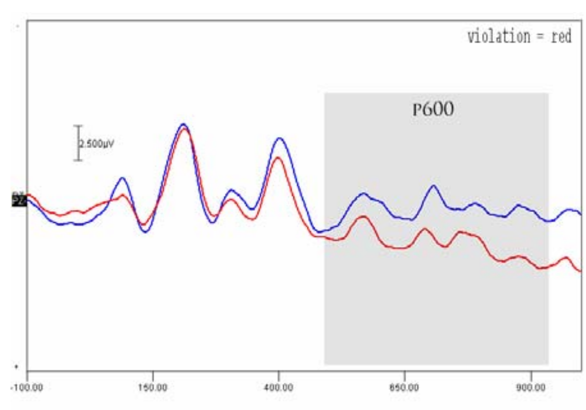

Figure 48. P600 in the '*tense-chi*' experiment, in a TLD group, Pz electrode

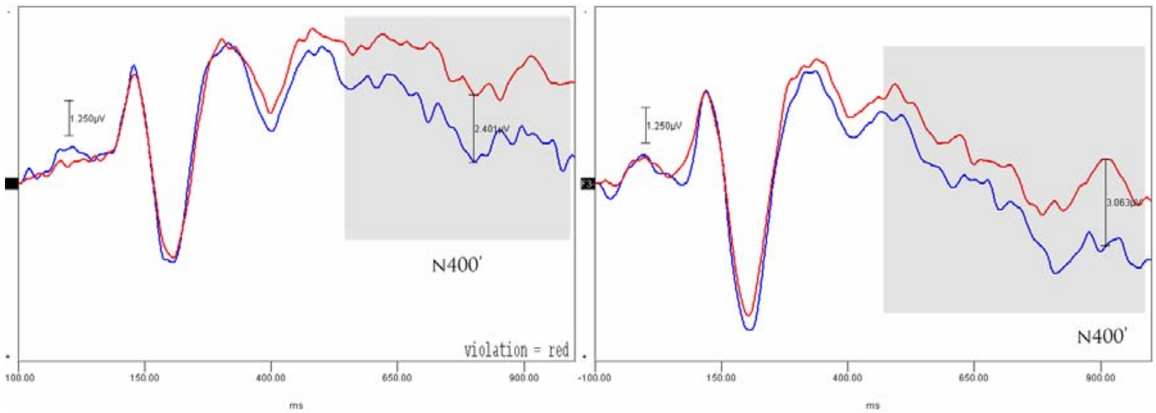

Figure 49. N400' in the '*tense-chi*' experiment, in a TLD group, left frontal electrodes (F7, F3)

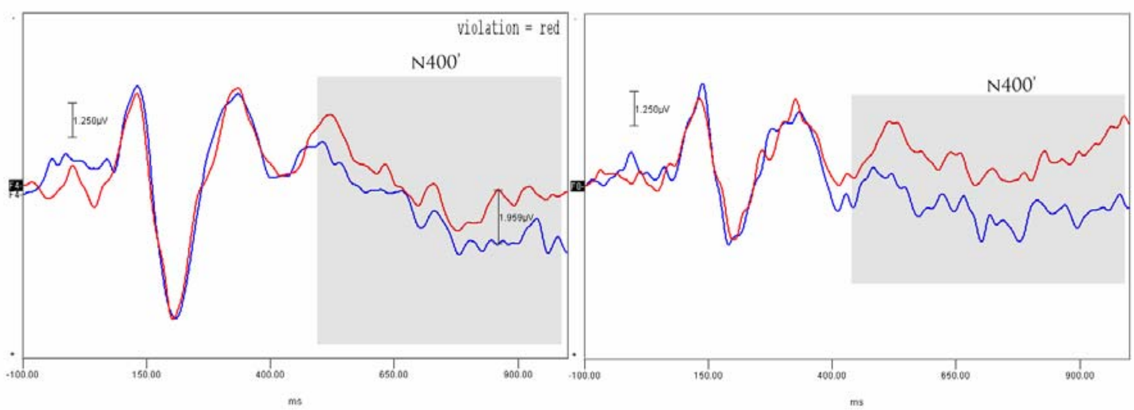

Figure 50. N400' in the '*tense-chi*' experiment, in a TLD group, right frontal electrodes (F4, F8)

The distribution map is given in Figure 51. For brevity, only the difference map is given. Figure 52 shows the left and right view for the late negativity.

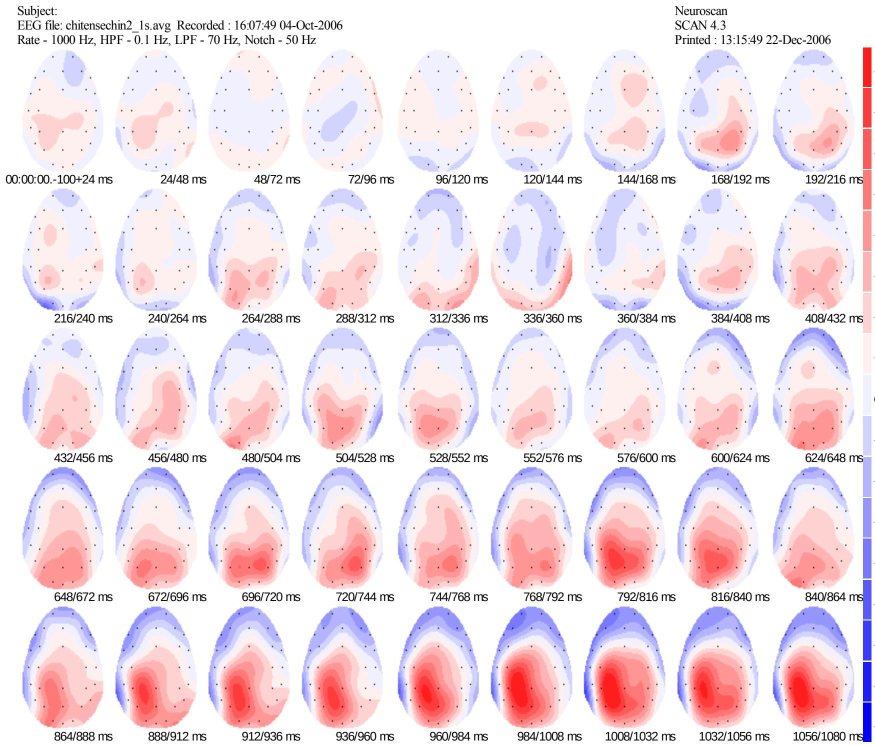

Figure 51. Difference map for ‘*tense-chi*’ experiment; TLD group

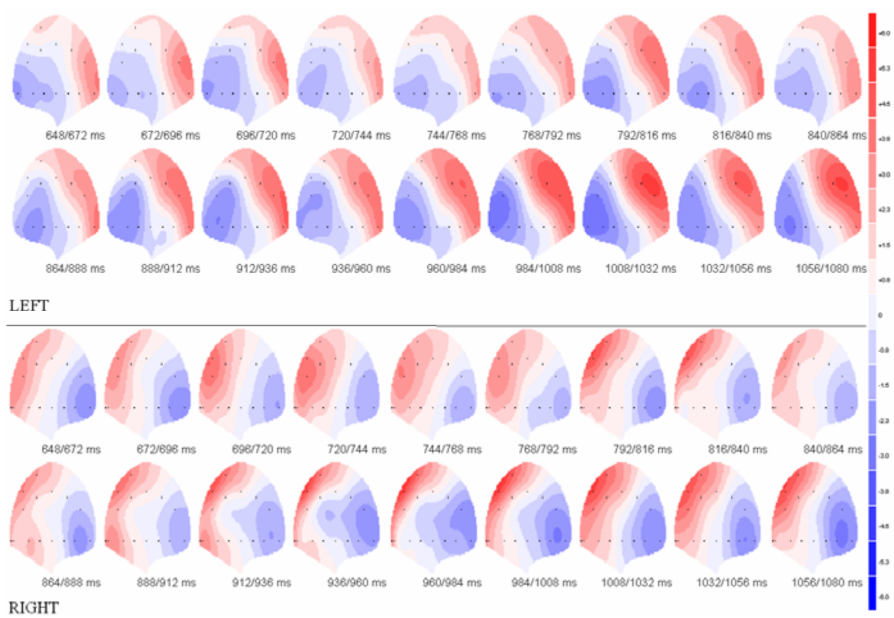

Figure 52. Left and right view, ‘*tense-chi*’ experiment; TLD group

The results of the statistical tests for the late negativity (650-750 ms interval) and P600 (600-700 ms interval) are given in Table 18 and 19.

Table 18. ANOVA results for the late negativity in '*tense-chi*' experiment, TLD

Electrode	F(1, 196)	p
F7	1817,993	,000*
F3	160,301	,000*
F4	305,226	,000*
F8	524,560	,000*
FT7	3366,888	,000*
FC3	19,945	,000*
FC4	1,674	,197
FT8	308,073	,000*

*Statistical significance at the p<0,001 level.

Table 19. ANOVA results for P600 in '*tense-chi'* experiment, TLD

Electrode	F(1, 196)	p
CP3	514,854	,000*
CPZ	1552,667	,000*
CP4	2406,748	,000*
P3	516,905	,000*
PZ	791,868	,000*
P4	2514,561	,000*

*Statistical significance at the p<0,001 level.

5.2.3. Comparison between adult control group and the group of TLD children

There is an obvious difference between the adult data and data obtained in a group of TLD children: the late negative wave has a frontal bi-hemispheric distribution, i.e. in the TLD children group it is not limited to the left frontal electrodes as in adults.

Generally, the comparison between the adult and TLD children data reveals three major differences. First, the amplitudes are generally higher in the TLD group (due to the differences in the skull thickness), as shown on Figure 53 and 54.

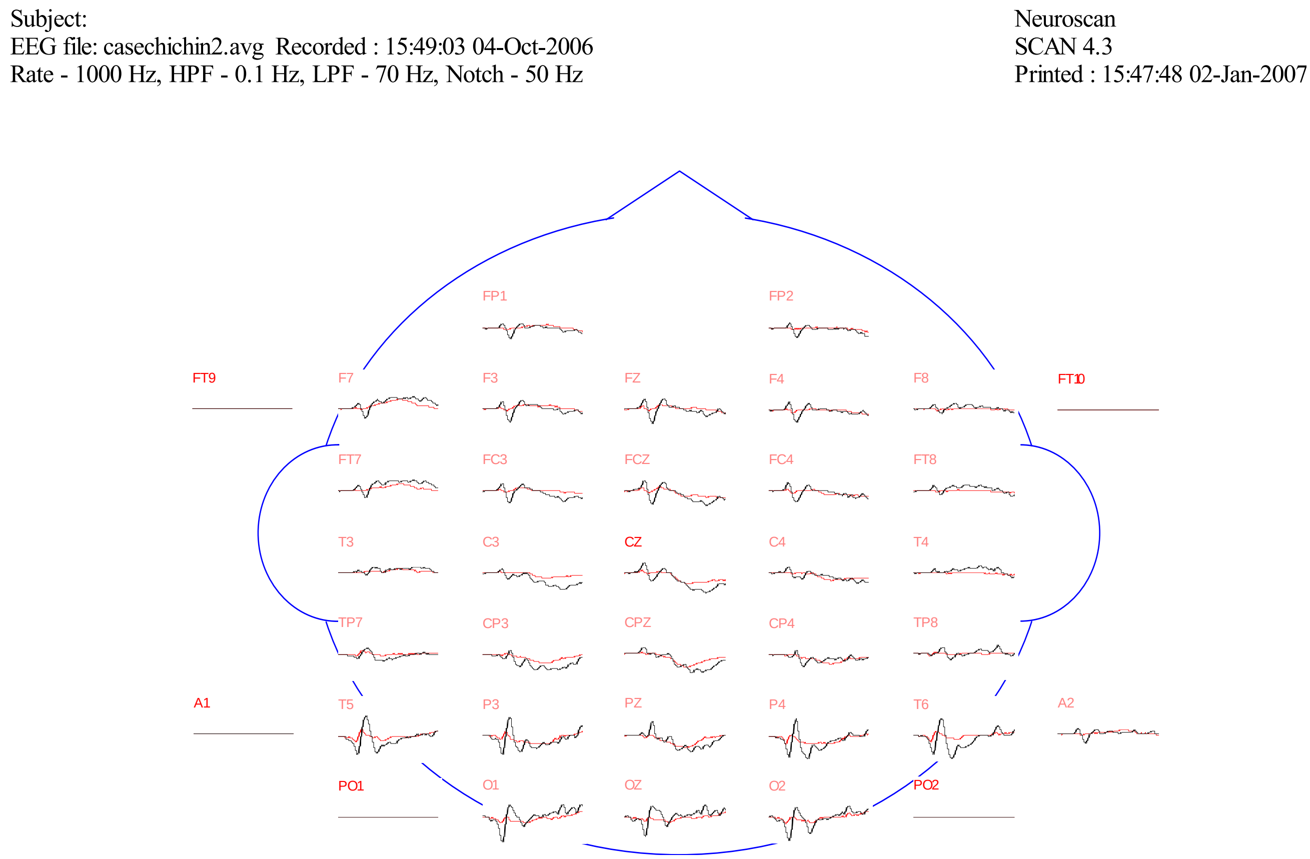

Figure 53. Difference between adults and TLD children, '*case-chi*' experiment, violation condition (children = black)

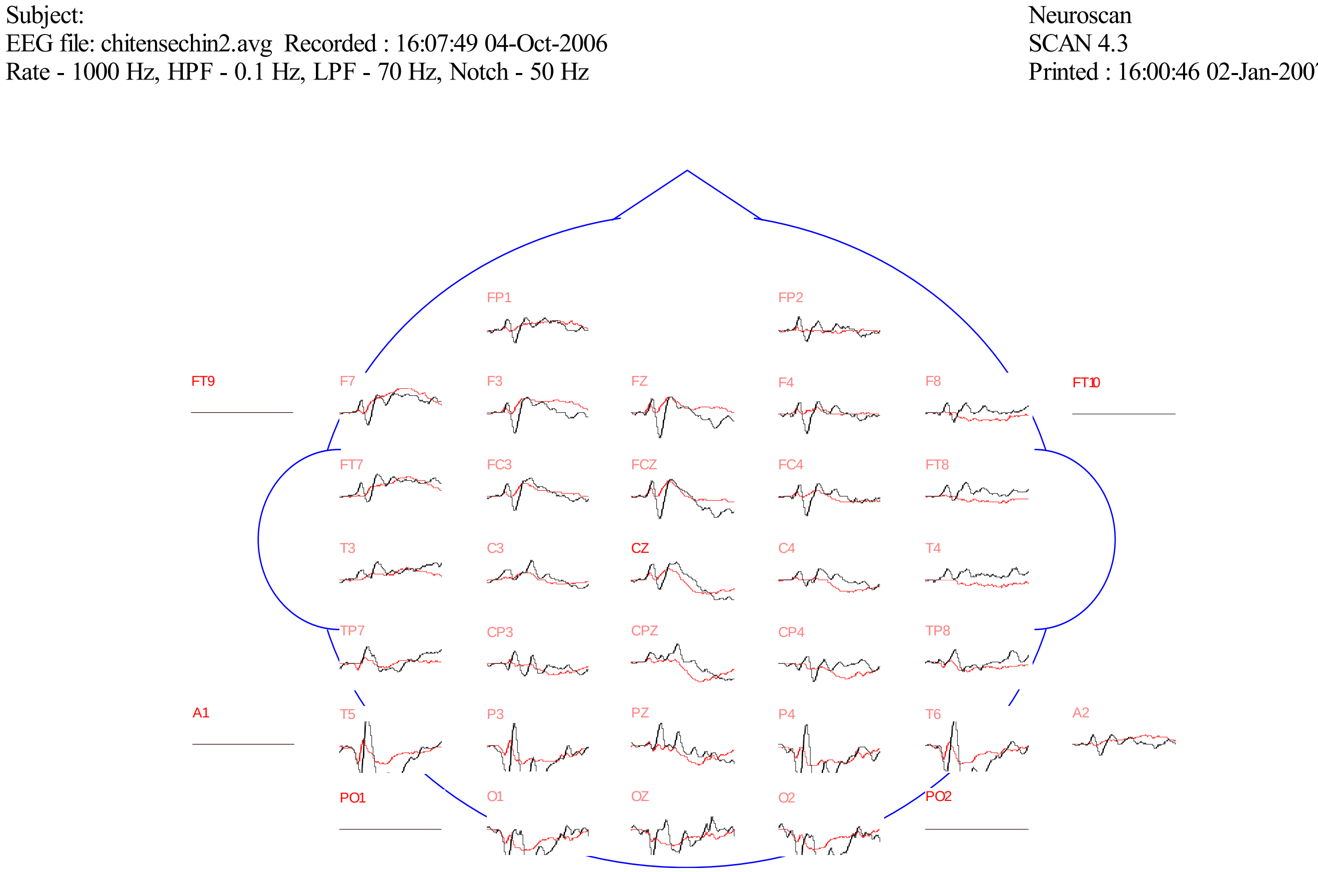

Figure 54. Difference between adults and TLD children, '*tense-chi*' experiment, violation condition (children = black)

Second, a shift in latency can be observed in the TLD children group, as shown on Figure 55 on which P600 in the '*case-chi*' experiment is compared on the Cz electrode.

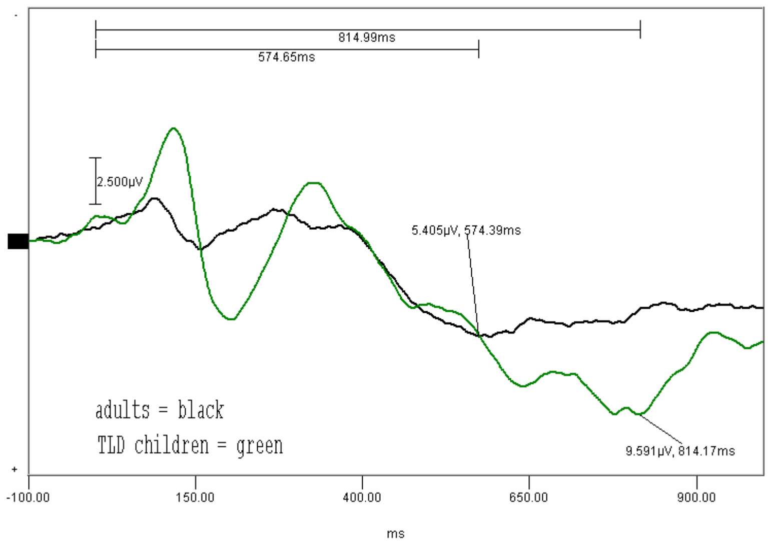

Figure 55. Difference in latency between adults and TLD children, '*case-chi*' experiment

Third, a difference in the distribution can be observed between adults and TLD children. In '*case-chi*' experiment the most striking difference is the absence of LAN. Instead, a negative deflection can be observed on the right hemisphere electrodes, parallel with P600 (distributed with the clear left hemisphere maximum). In the '*tense-chi*' experiment the distribution of the negative wave labeled as N400' is different: the wave is the most prominent on the both left and right frontal electrodes, but not on the middle electrodes on which it is perhaps blurred by a broad overlapping P600. Although for the sound developmental reasoning based on ERP data more data should be collected, a simple reasoning seems justified: broader and later characteristic ERP components obtained in TLD children reflect developmental course in which more effective adult-like processing corresponds to earlier and narrower (in terms of topographic distribution) components which TLD children at age 9-11 have not reached yet.

5.2.4. Children with SLI

Behavioral results. Children with SLI were tested on a number of variables to determine their language status. The results are given in Tables 20, 21 and 22 (phonology, morphology & syntax and lexicon & semantics). Boys are labeled B1, B2 and B3, while the girl is marked as G1. As explained in the *Materials & Method* section, the results are given descriptively, on a *poor-moderate-good* scale. The reason is, as mentioned above, that these tests are working materials designed primarily for pre-school age. The materials have a simple scoring system based on the number of correct answers. In addition, incorrect answers are recorded for the interpretation of child's error. No age-tuning of a kind developed for, for example, Peabody Picture Vocabulary Test is possible. Some tests are therefore too easy for TLD children between 9 and 11 and they usually reach ceiling. However, SLI children of the appropriate age do not show the ceiling effect on these materials. Phonological analysis and synthesis test is a good example for this: while this task is far too easy for the TLD children, SLI children still make errors on this test.

TLD children of age between 9 and 11 still make errors on some of the test materials: case and number markings that involve morphonological changes, for example, persist to be problematic even for school-age children. However, while committing morphonological errors, TLD children of age between 9 and 11 generally do not mix cases (e.g. Dative instead of Genitive), in other words, they have acquired the case system of Croatian. SLI children do commit this sort of error. The test material that includes various Croatian noun paradigms with various morphonological rules is thus only *relatively* good instrument for discriminating SLI children: while both groups make errors, the *kind* of error is actually relevant. Numerical results in which both groups would be 'punished' by low scores, but for different reasons, would be misleading. Therefore, more descriptive scoring was adopted, which allowed for judging the kind of error committed by SLI child and which put SLI child in relation to the TLD child, a relation that could be lost if only raw numerical results were used.

Table 20. Individual results on language tests in SLI group; phonology

Phonology:							
Discrimination				**Rapid naming**			
B1	B2	B3	G1	B1	B2	B3	G1
moderate	good	good	good	poor	moderate	moderate	Poor
Phon. analysis and synthesis; deletion of phonemes in words				**Word Repetition: phonologically similar words**			
B1	B2	B3	G1	B1	B2	B3	G1
poor	moderate	moderate	poor	poor	poor	poor	Poor
Word Repetition: semantically similar words				**Pseudo-words repetition**			
B1	B2	B3	G1	B1	B2	B3	G1
poor	poor	poor	moderate	moderate	good	good	Moderate
Phonological memory (forward)				**Phonological memory (backward)**			
B1	B2	B3	G1	B1	B2	B3	G1
moderate	good	moderate	moderate	moderate	moderate	poor	Moderate

Table 21. Individual results on language tests in SLI group; morphology & syntax

Morphology & Symtax:							
Noun morphology:				**Prepositions (comprehension & production)**			
B1	B2	B3	G1	B1	B2	B3	G1
poor	moderate	poor	moderate	poor	poor	poor	Good
Verb morphology: prefixation				**Possessive relations**			
B1	B2	B3	G1	B1	B2	B3	G1
moderate	poor	poor	poor	poor	moderate	moderate	moderate
Sentence repetition							
B1	B2	B3	G1				
poor	poor	poor	poor				

Table 22. Individual results on language tests in SLI group; lexicon & semantics

Lexicon & Semantics:							
Lexical production:				**Antonyms:**			
B1	B2	B3	G1	B1	B2	B3	G1
good	good	moderate	good	poor	moderate	poor	Moderate
Peabody Picture Vocabulary Test:				**Homonyms:**			
B1	B2	B3	G1	B1	B2	B3	G1
*75%	*73%	72%	*77%	poor	moderate	poor	Poor
Synonyms:							
B1	B2	B3	G1				
poor	poor	poor	poor				

*Percentage of the correct answers in relation to the maximal values for the appropriate age.

The results show overall low results. Phonological skills showed to be better in respect to other language components most probably due to long exposure of all children to therapy in which phonology was particularly exercised. However, repetition of words showed to be too difficult phonological test, be it the repetition of phonologically or semantically similar words or pseudo-words. Quick naming also showed lower scores, as all tests in which time dimension was critical. Discrimination between phonologically similar words proved to be good. At least, this is a good indication that the children included in the study did not have perceptual problems. As the children were included in therapy, better results on tests that did not require quick reaction indicate learned, explicit knowledge instead of automatic acquired skills.

Morphology and syntax proved to be affected in all children, but for at least two children problems in morphology could be explained as a consequence of poor phonological skills, as these children were diagnosed as phonological SLI. Mixing cases was frequently recorded for all children. In tests in which prefixes had to be added to the verb root in order to derive perfective meaning children with SLI regularly used compensatory mechanisms to convey the perfective meaning and avoided the target verb form: describing a picture on which a rabbit was digging a carrot, SLI children correctly used the imperfective form. However, when the picture showed the rabbit with the carrot dug out, the SLI children typically answered that the rabbit *finished digging*, avoiding the target form (he *dug* it *out*). All SLI children showed poor skills on sentence repetition task. Usually, they would drop out all words that were not crucial for the basic meaning of a sentence, in most cases adjectives and adverbs.

Lexical skills are also affected in the group of SLI children. Synonyms proved to be especially difficult; children recognized 1 to 3 out of 9 synonyms while recognizing 5 to 8 homonyms (out of 15), for example. On Peabody Picture Vocabulary Test SLI children achieved 72-77% score for their age which is a valuable indication of language impairment due to the fact that PPVT is a standardized test.

Generally, the results are quite similar for all children. They are usually poor-to-moderate or moderate-to-good for all tests except tests of production and comprehension of prepositions where the girl achieved good results (7/8 and 8/8 correct answers) while the boys failed. This constrained range of results indicates that the chosen group of SLI children was relatively homogenous which is important for further electrophysiological experiments. Finally, in conversation before the testing and after it the children frequently committed phonological errors (metatheses and deletions) characteristic for phonological impairment.

Electrophysiological results. Overall similarity of results obtained in a group of SLI children justifies the analysis of the results by grouping them in grand averages. The grand average for '*case-chi*' experiment is given in Figure 56.

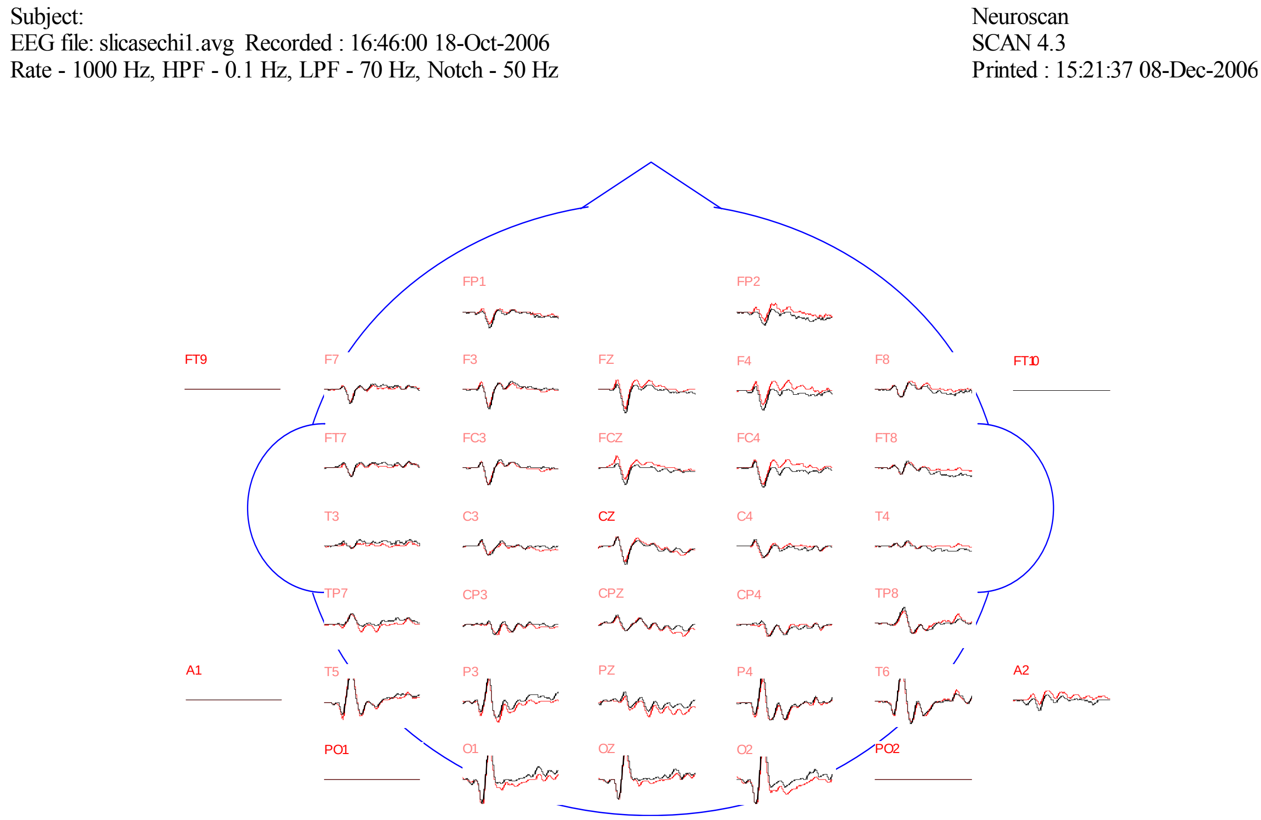

Figure 56. Grand average in ‘*case-chi*’ experiment, SLI children

A closer look reveals very small differences between the experimental conditions. Figure 57 reveals no differences at the left frontal electrode sites, while Figure 58 represents a negative deflection obtained only at the right frontal electrodes.

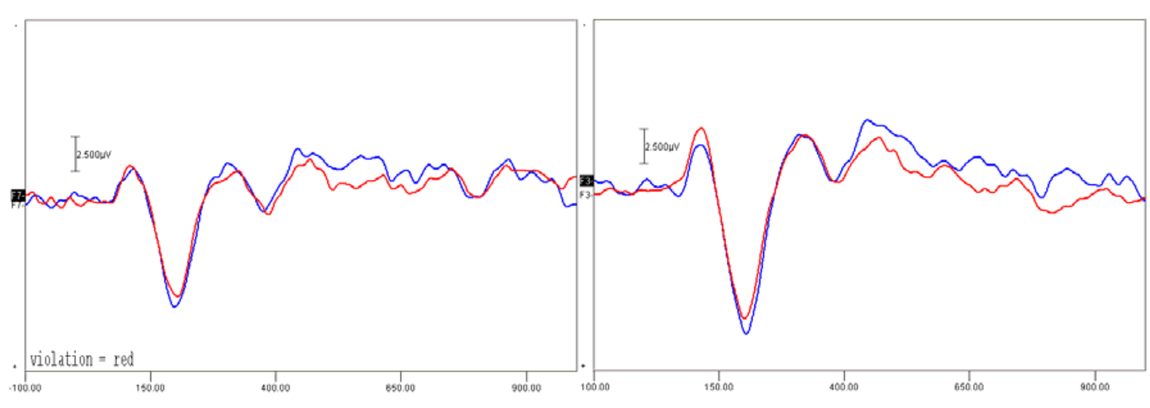

Figure 57. ‘*Case-chi*’ experiment, left frontal electrodes, SLI group

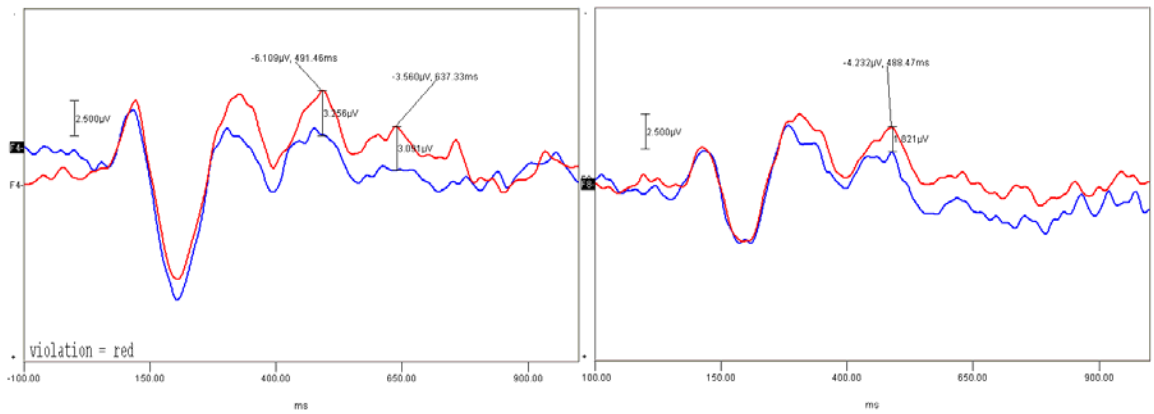

Figure 58. Negative deflection obtained at right frontal electrodes (F4, F8)

Late latency of the negative deflection can be recognized (≈640 ms). In addition, a weak P600 effect can be recognized on the central parietal electrodes, but with a later latency (≈850 ms), as shown on Figure 59.

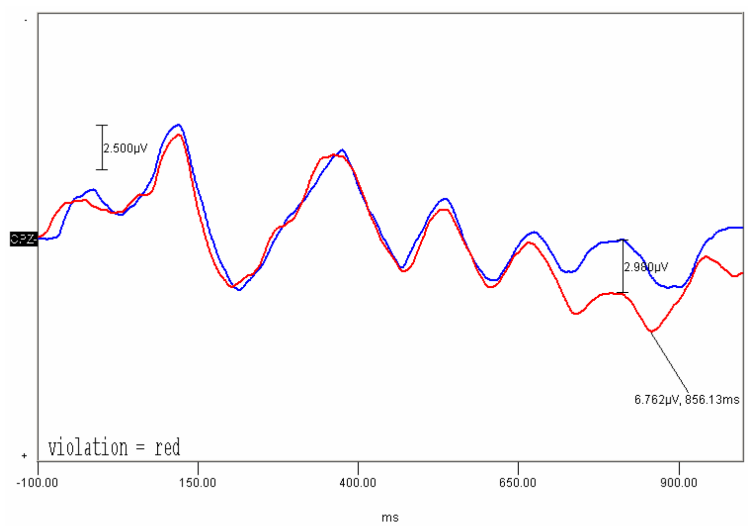

Figure 59. P600 in the '*case-chi*' experiment, SLI group

Figure 60 provides distribution map for the '*case-chi*' experiment. Persistent negative deflection at the right frontal electrode sites and a weak P600 effect are clearly visible on the difference map.

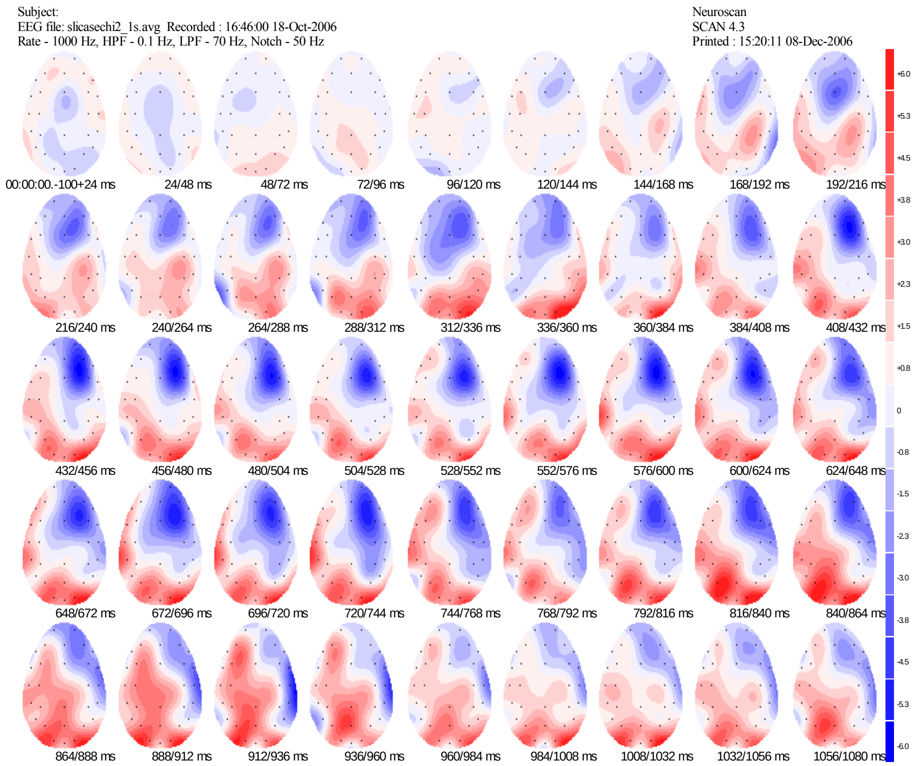

Figure 60. Difference map in the '*case-chi*' experiment, SLI group

Statistical tests show that the difference between the experimental conditions is not significant on the left frontal electrodes in the LAN range, but that it is significant on the right frontal electrodes. In the later interval, 600 – 700 ms the difference proved to be statistically significant, as shown on Table 23.

Table 23. ANOVA results for frontal electrodes, '*case-chi*' experiment, SLI group

	300-400 ms interval		600-700 ms interval	
Electrode	F(1, 196)	p	F(1, 196)	p
F7	2,928	,089	222,775	,000*
F3	,660	,418	285,276	,000*
F4	310,905	,000*	2984,802	,000*
F8	32,777	,000*	340,685	,000*

*Statistical significance on p<0,001 level found.

Table 24 provides statistical data for the P600 effect. The results show the lack of significance on the right centro-parietal and parietal electrodes (CP4, P4) in the P600 interval. The results are consistent with the late broader positive wave, as visible on Figure 59.

Table 24. ANOVA results for centro-parietal electrodes, '*case-chi*' experiment, SLI group

	600 – 700 ms interval		800 – 900 ms interval	
Electrode	F(1, 196)	p	F(1, 196)	p
CP3	213,971	,000	404,358	,000
CPZ	462,219	,000	122,132	,000
CP4	1,494	,223*	73,459	,000
P3	3198,899	,000	301,665	,000
PZ	554,486	,000	260,533	,000
P4	3,652	,057*	9,293	,003

*Statistical significance on p<0,001 level found.

Figure 61 shows grand average for the '*tense-chi*' experiment in the group of SLI children. The grand average over all electrodes reveal very small differences between the experimental conditions.

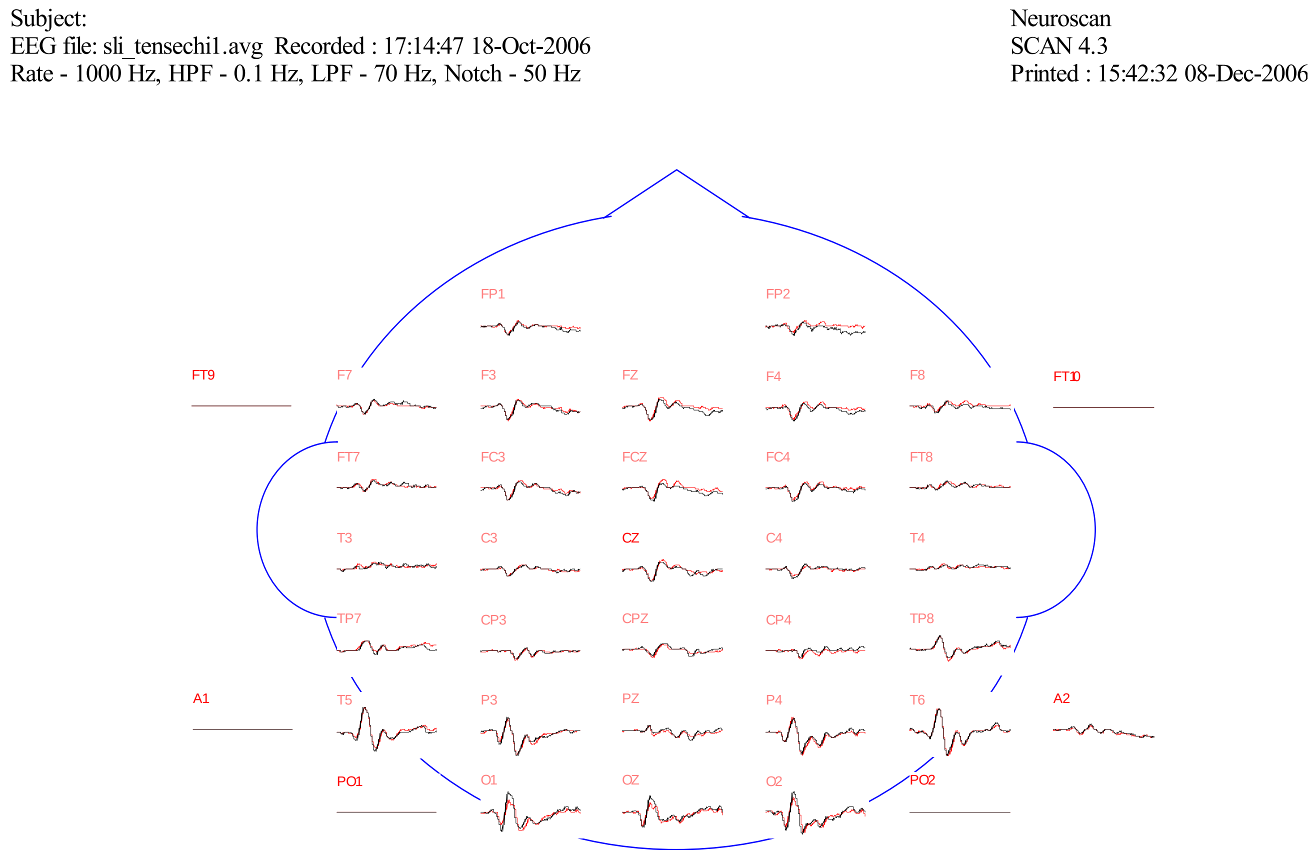

Figure 61. The grand average in the *'tense-chi'* experiment on a group of SLI children

Characteristic late negative deflection is not obtained on the left frontal electrodes. A small effect is, however obtained on the central and right frontal electrodes (Figures 62 and 63).

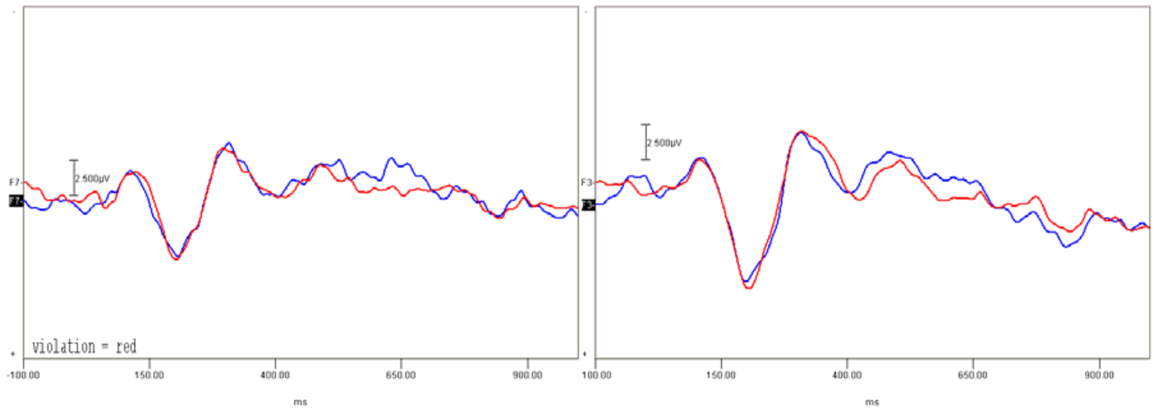

Figure 62. Left frontal electrodes (F7, F3), '*tense-chi*' experiment, SLI group

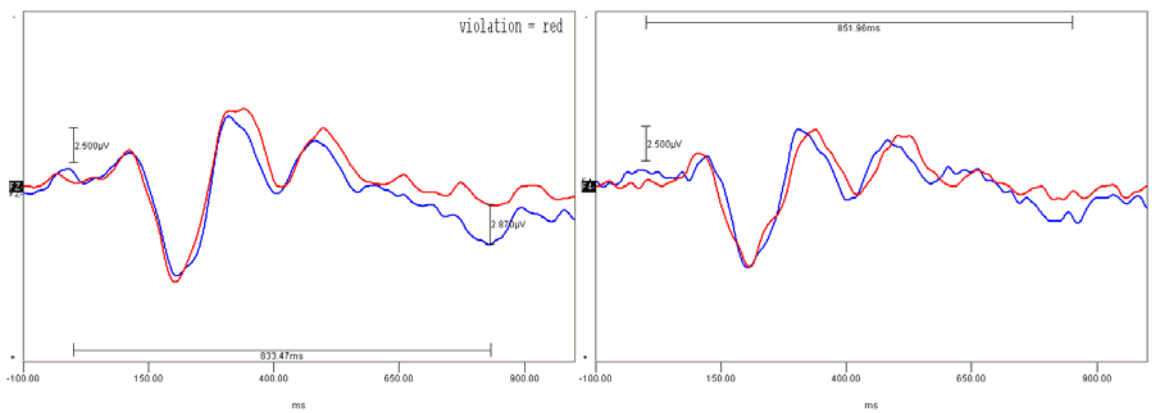

Figure 63. Central and right frontal electrodes (Fz, F4), '*tense-chi*' experiment, SLI group

The P600 clearly observed in the group of adult speakers and children with TLD is not visible in the results obtained in the group of children with SLI. Statistical tests provide further information on the obtained data. Table 25 shows the results for the frontal electrodes in the 500 – 800 ms interval, while Table 26 shows the results for the centro-parietal electrodes.

Table 25. ANOVA results for the frontal electrodes, '*tense-chi*' experiment, SLI group

Electrode	F(1, 596)	p
F7	364,777	,000**
F3	1,424	,233
FZ	208,675	,000**
F4	129,631	,000**
F8	210,669	,000**

**Statistical significance found on p<0,001 level.

Table 26. ANOVA results for the centro-parietal electrodes, '*tense-chi*' experiment, SLI group

Electrode	F(1, 596)	p
CP3	4,458	,035*
CPZ	,116	,733
CP4	218,057	,000**
P3	1,267	,261
PZ	3,064	,081
P4	16,939	,000**

*Statistical significance found on p<0,05 level.
**Statistical significance found on p<0,001 level.

Finally, distribution map is provided to show the topographic data of the difference between the experimental conditions. The map reveals no consistent difference before ≈800 ms. In the late interval, 800-1000 ms a slow positive wave at the frontal electrodes together with the positive wave on the central and parietal electrodes can be observed, as given on Figure 64.

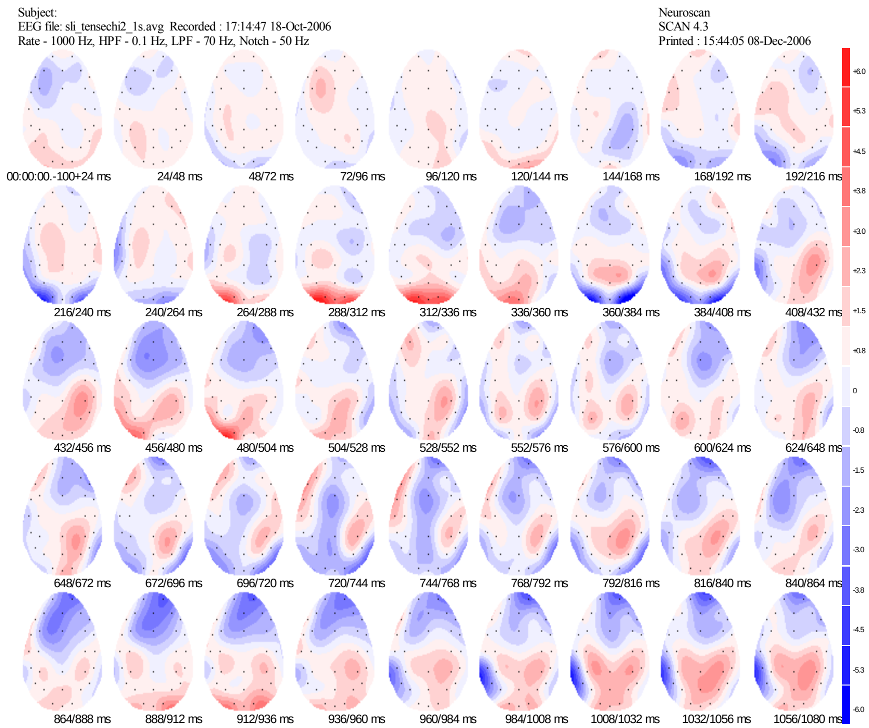

Figure 64. Difference map in the '*tense-chi*' experiment, SLI group

5.2.5. Comparison between TLD and SLI children

Figure 65 shows an overview of the violation conditions obtained for '*case-chi*' experiment in the group of TLD and SLI children (SLI children are represented in red).

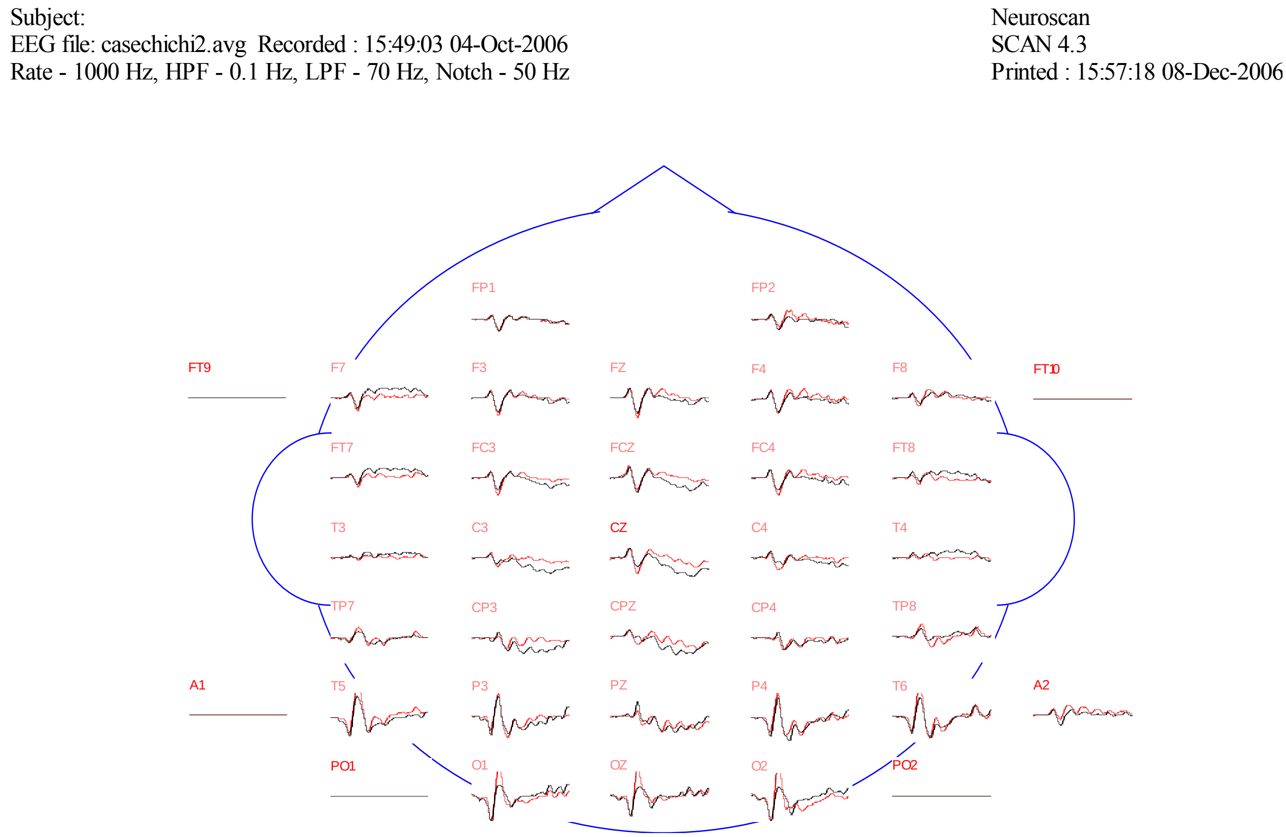

Figure 65. A comparison between TLD and SLI group, '*case-chi*' experiment (SLI group = red)

Figure 65 shows much "higher" and "deeper" effects obtained in the group of TLD children. This is clearly visible on Figure 66: P600 effect on the CPz electrode is not only smaller in comparison to TLD children, but has a later latency (74 ms). Figure 67 shows both conditions for both groups of children for the neighboring Cz electrode. Smaller difference between the experimental conditions in the group of children with SLI is clearly visible.

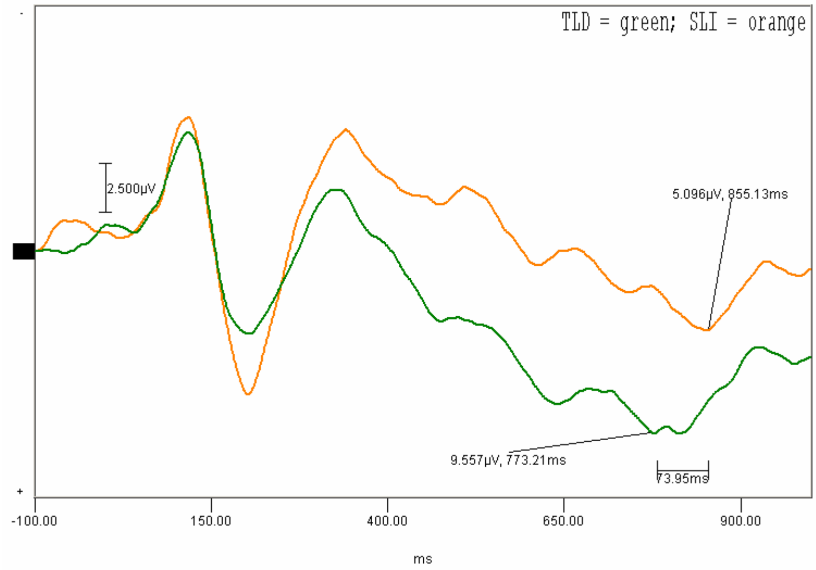

Figure 66. A comparison between TLD and SLI group: P600 on CPz electrode, violation condition

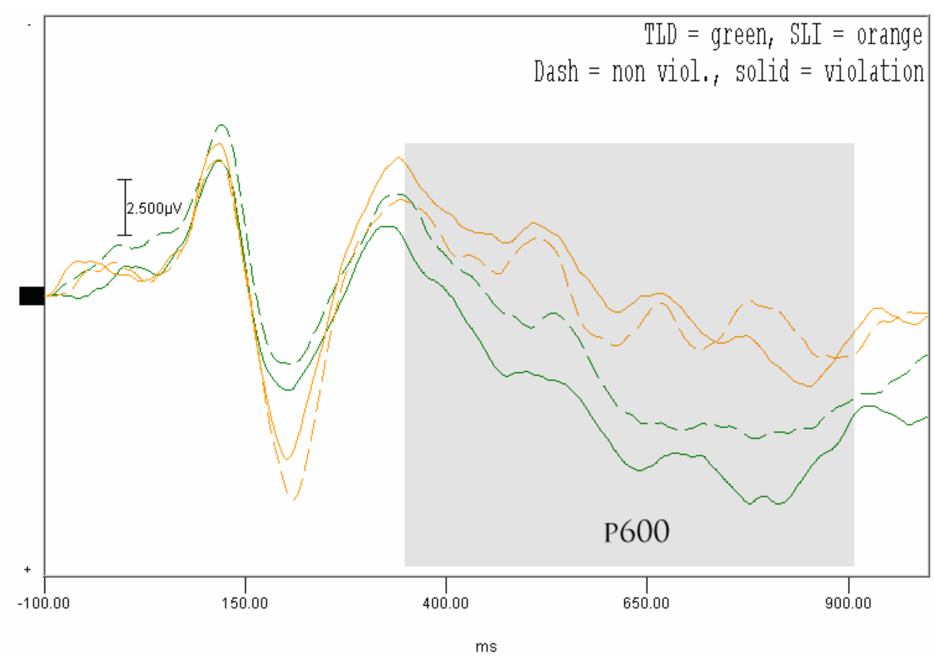

Figure 67. A comparison between TLD and SLI group: P600 on Cz electrode

The same comparison can be made for '*tense-chi*' experiment. Figure 68 shows the overall results of the comparison of all electrodes for the violation condition.

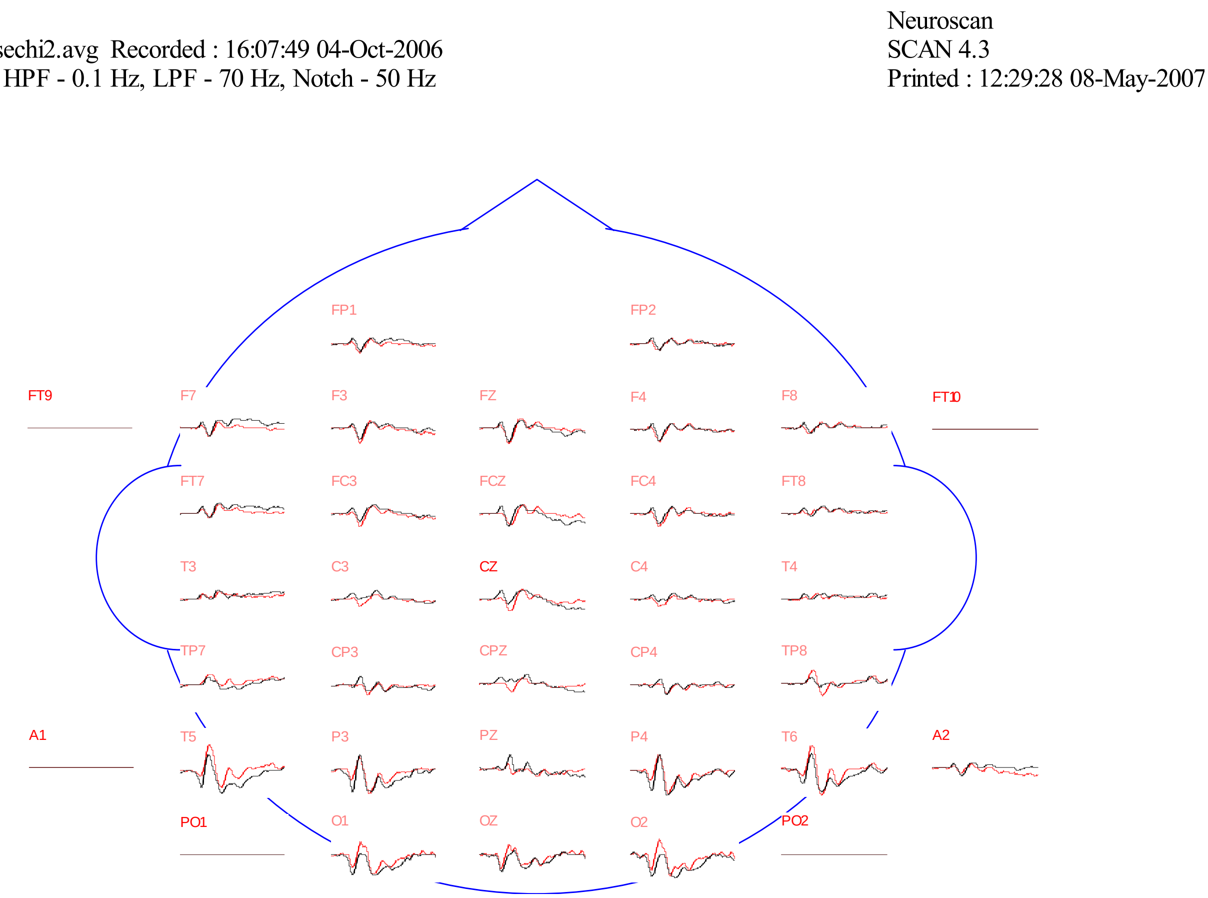

Figure 68. Comparison between TLD and SLI group in '*tense-chi*' experiment, violation condition (SLI = red)

Again, larger negative deflection at the frontal electrodes is visible in the TLD group as well as the more prominent P600 effect on the centro-parietal electrodes. Figure 69 shows a prominent negative deflection in the violation condition obtained in a TLD group at the left frontal electrode (F7). This effect is missing in the group of SLI children. Similar results for P600 can be seen on Figure 70.

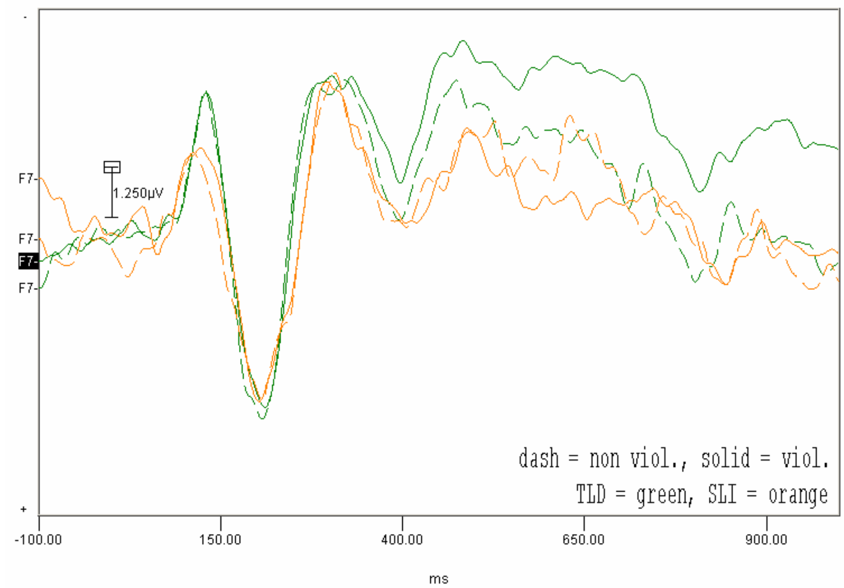

Figure 69. A comparison between TLD and SLI children, ‘*tense-chi*’ experiment, F7 electrode

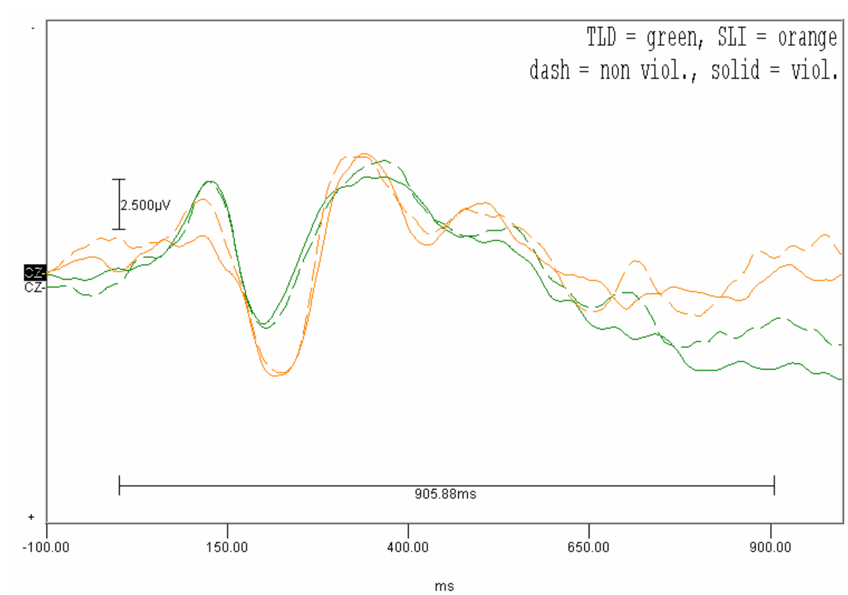

Figure 70. A comparison between TLD and SLI children, ‘*tense-chi*’ experiment, Cz electrode

5.3. General Discussion

5.3.1. Sentence comprehension in adults

The four experiments on adult Croatian speakers show that syntactic processing is not a unique process. It can be dissociated to other, more elementary processes that contribute to the building of the sentence structure and its interpretation. In this study this dissociation is defined in terms of the Role and Reference Grammar. According to this linguistic theory it is claimed that the elements of the operator projection are 'quite different from predicates and their arguments' (Van Valin, LaPolla, 1997:40). Electrophysiological results confirm this claim corroborating the idea that this linguistic theory can be taken as a processing model, as well. However, as the obtained results reveal, the electrophysiological trace of processing the data represented on the operator projection does not reveal a new syntax-related component, but indicates processes that are related to the integration of a part of sentence meaning, i.e. the point in time at which the action occurs (the difference can be characterized as a difference *within* a component, as the label N400' suggests. This label emphasizes the functional side of the obtained component, i.e. semantic processing). It can be suggested that in order to explain these results, RRG - taken as a processing model - should be extended with another kind of syntax-to-semantics mapping in which elements of the operator projection would be mapped into a set of relations defined by philosophical logic (Van Benthem, 2002), as suggested above. In other words, it is not just the argument structure that is reconstructed in the sentence comprehension, but also temporal or spatial relations, speaker's beliefs or probability of the action described in a sentence. A prediction can be made: in languages with, for example, evidentials late negativity similar to the N400' obtained in '*tense*' experiment could be obtained.

The obtained dissociation of various elements of syntactic processing confirms hypothesis 1.1. which states that different aspects of syntax will elicit different electrophysiological responses. In particular, hypothesis 1.1.1 which predicts ERP components in '*case*' experiment can be fully confirmed. In this experiment LAN and P600 components have been obtained, as predicted by the hypothesis. However, the hypothesis 1.1.2. stating that '*tense*' experiment would elicit only P600 showed to be only partially true: while P600 component *was* obtained, the experiment had rather unexpected results: a broad late negative wave on left frontal electrodes labeled N400'. This result, in turn, corroborates the dissociation between two parts of syntax, as claimed in the hypothesis 1.1.

5.3.2. Developmental data

Children with TLD. It can be stated that the task of comprehending a sentence is thus even more demanding than it is generally thought with different processes taking part in a brief time window. Developmentally, this means that a vast quantity of data should be processed with a limited mechanism. Delay in latency observed in the TLD children group can be a good indication of a mechanism that is – at the age of 9-11 – not fully developed. This is contrary to the predictions stated in the hypotheses 2.1. and 2.1.1. Therefore, these hypotheses cannot be confirmed. The hypotheses were based on the fact that at that age children with TLD have acquired the both tense and case system of

Croatian. In this respect ERP method can provide developmental information that would be difficult to obtain using behavioral methods only.

The absence of LAN in the group of children with TLD in '*case-chi*' experiment (and observed late negativity with right hemisphere maximum at ≈900 ms) together with broader (bi-hemispheric) distribution of the late negativity in '*tense-chi*' experiment indicate differences in sentence processing between children and adults. If one speculates about the same functional value of the right negative deflection obtained in children and LAN obtained in adults in '*case-chi*' experiment, a claim could be made about both different neural substrates and about the difference in the effectiveness of processing. These results are in accordance with the mentioned view that children process language with 'inefficient' means and that children with SLI persist in this inefficient processing (Bishop, 2000).

Children with SLI. If the processing capacity is even more limited in children with SLI (regardless of the nature of the limitation), further slowing down will take place causing, eventually, a breakdown of sentence processing.

The limitations regarding rapid processing of a large quantity of data in the group of SLI children can be observed on a behavioral level: SLI children proved to be particularly weak in tasks where time or time limit was an important factor (e.g. repetitions, quick naming, v. Table 20-21). These behavioral data are in good accordance with the electrophysiological data obtained in this group of participants; in particular with (1) lack of error detection as observable in a small or nonexistent difference between experimental conditions in the SLI group; and (2) later latencies of characteristic peaks of ERP components (if they could be identified at all in the SLI group given the -100 – 1000 ms window).

However, one more comparison should be made. The difference *between the experiments* is very small in the group of children with SLI. Figure 71 shows *violation condition* in both ‘*tense-chi*’ and ‘*case-chi*’ experiment for all electrodes. The similarity is especially observable on the frontal and central electrodes where the dissociation of the syntactic processing should have been most prominent (Figure 72).

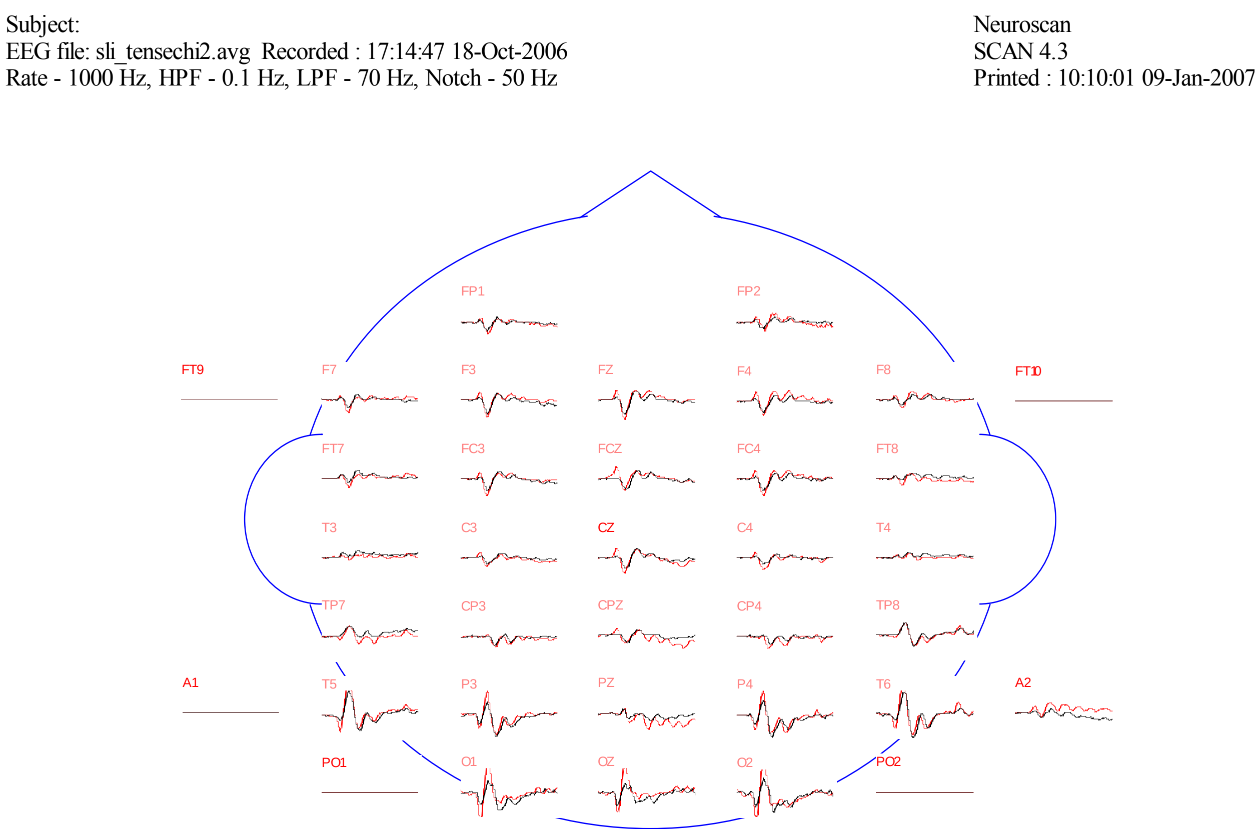

Figure 71. Difference between the experiments in the SLI group (violation condition, black=’*tense-chi’*, red=’*case-chi*’ experiment)

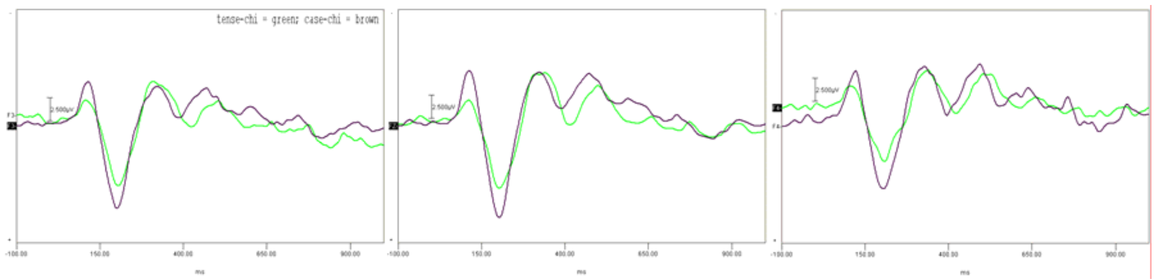

Figure 72. Difference between the experiments in the SLI group (F3, Fz, F4 electrodes)

These results indicate that the dissociation between the processes related to the constituent and operator projections of the clause does not exist in the group of participants with SLI. Since the dissociation is most prominent in the group of adult speakers, modularization of language processing can be understood as a final stage of language development and optimal way of language processing. Children with SLI do not process sentences this way, but instead, they process the sentences in an impropriate way. Perhaps they never reach the final stage in the language development and develop some compensatory mechanisms (good behavioral results of the SLI children who attended therapy and, in fact, learned the tasks through practice can be a behavioral correlate of these mechanisms).

These results are not in accordance with the mentioned sentence task experiment in van der Lely & Fonteneau (2003) in which a semantic component (N400) was obtained *instead of* syntactic components (LAN and P600) in a group of G-SLI children. They interpreted the findings as a consequence of a deficit in the syntactic module; therefore, the G-SLI children process sentences only *semantically* or, to use different terminology, *agrammatically*. But the presupposition of this interpretation is that children, normally, process sentences the same way as adults and that only the grammatical module is affected. Our data suggest that the modularization is the final state of language development, perhaps an evolutionary optimal way of processing language data with limited capacities. SLI children do not reach this stage, not in the extent their peers do.

The obtained data show how conservative the hypotheses 2.2., 2.2.1 and 2.2.2. are. They can all be confirmed since they predicted only latency shifts for relevant components. Indeed, the latencies of the P600 were later both in '*case-chi*' and '*tense-chi*' experiments in the SLI group, as predicted in the H2.2.1 and H2.2.2. The only prediction that could not be confirmed was the later latency of LAN in '*case-chi*' experiment due to the fact that LAN was not obtained in this experiment neither in the TLD group nor in the SLI group (H2.2.1.). Lack of difference between experiments was not directly predicted, but it is exactly this similarity between results in different experiments which allow for making a stronger claim: since SLI children lack dissociation between different aspects of syntactic processing, they lack adult-like modularized sentence processing. Compensatory mechanisms that can be observed on a behavioral level correspond to this developmental trait of children with SLI. In this respect the hypothesis 2.3. stating that it is not to be expected that children with SLI lack only one language component (but that the deficit is more general, on a processing level) can be fully confirmed.

5.3.3.. The results in the light of language processing models

The results of the '*case*' and '*gender*' experiments correspond to numerous ERP experiments in which both LAN and P600 components were obtained in some sort of grammatical violation paradigm. While P600 is usually related to either integration processes (especially if the target word is in the sentence final position) or repair and reanalysis (particularly in serial processing models), there is no general agreement in the functional analyses of LAN since it can be obtained in a number of experiments in which some aspect of morphosyntax is violated. The results obtained in '*case*' and '*gender*' experiment fit into the model proposed by Bornkessel & Schlesewsky (in press), a model that is of interest here because it uses some notions of RRG. In their model LAN is functionally related to establishing agreement and linking (macrorole mismatch). While the model is predominantly serial (three phases, with parallel processes within each phase), it is sensitive to the recent findings which weaken the opposition between syntax related and semantics related components in electrophysiological research in sentence comprehension (Kuperberg et al., 2006, Kim & Osterhout, 2005) especially when grammatical categories interfere with thematic relations (in Kim & Osterhout experiment thematic roles were inversed as in '*at breakfast the eggs would eat…*' where (morpho)syntax and semantics are interwoven). Therefore, Dative where Accusative is expected might be interpreted as thematic role violation (non-macrorole instead of macrorole) with LAN as an electrophysiological signature obtained in similar experiments for e.g. Dutch and German. The same components, LAN and P600 obtained in '*gender*' experiment can be interpreted as agreement error; again, in accordance with eADM model. At the same time it should be noted that all results that make the distinction between semantic and syntactic processing somehow relative, do not corroborate Ullman's declarative-procedural model (Ullman, 2004) in which syntax is related to procedural memory and semantics to declarative. In addition, if one accepts the idea that a word contains some syntactic information (e.g. logical form of the verb in RRG or word templates in MUC (Hagoort, 2005, Vosse & Kempen, 2000)) a chance to dissociate syntax and semantics and obtain some trace of pure syntactic process seems rather slim especially for language such as Croatian, in which grammatical violations such as violations in case carry important semantic information about thematic relations.

The eADM model does not address the processing that is related to the operator projection. The model accounts only for the processing of core constituents (verbs and arguments). Therefore, the '*tense*' experiment is not relevant as evidence in favor or against this model. Since there are no predictions regarding ERP components that could be expected in the '*tense*' experiment, it cannot be said that the late negativity was not predicted by the eADM (as it cannot be said that it was predicted). In short, the '*tense*' experiment is not a test for the eADM. However, together with the '*quantifier*' experiment in which N400 was obtained, the results of the '*tense*' experiment (N400') may suggest possible future developments of eADM in this direction. As already stated (pp. 106-107), syntax-to-semantics interface may be supplemented with a linkage between operator projection and a set of relations defined by philosophical logic. Role and Reference Grammar provides an account for the obtained results, i.e. it can capture a generalization in this respect: both N400 and N400' represent processes related to the operator projection of the clause (or NP). As eADM says nothing about operators, there is nothing in the model that speaks against such a development.

In short, the results confirm that the processing related to the information represented on the constituent and operator projection is cognitively different and more, that the results obtained in the experiments that manipulate the operator projection are similar across experiments. The second point (i.e. the functional correspondence of components at different latencies) indicates what kind of a model could explain the results. The same latency of P600 and N400' suggest that immediacy models (such as MUC model in Hagoort, 2003, 2005) are good candidates due to an important feature of these models: the information is processed when it becomes available, not according to some fixed order. The information about the time of the event described in the stimulus sentences is, on the one hand not required for the thematic role assignment (therefore, no LAN effect), but, on the other hand, it is required for the overall integration of the sentence meaning (therefore, N400' co-occurs with P600). It should be noted that this reasoning still has a high degree of speculation due to the fact that visual stimuli are not suitable for these inferences. Acoustic stimuli, for which one can say what information is available at some point in time as in Friederici's (2002) and Hagoort's experiments. Nevertheless, the results of the '*case*' and '*tense*' experiment actually corroborate RRG as a language processing model and eADM, the model which is based on RRG, to the extent the model addresses the issues raised by the interpretation of the experiments.

The two experiments performed on a group of children with TLD and children with SLI are hardly sufficient to make new discoveries about the nature of SLI. The absence of LAN in the TLD group and a right hemisphere negative deflection with a shift in latency are consistent with the Bishop's (2000) view on 'how brain learns language'. According to this view, language development does not consist only of growth, but also on the refinement and reorganization processes. She uses a bush as a metaphor: its cultivation in a garden does not consist only of watering, but also of trimming. The bush metaphor is even more convincing when compared with the anatomical facts about brain development in infancy and childhood, in particular with the observed decrease in the number of synapses, a decrease which lasts until the end of puberty (Judaš & Kostović, 1997, Benes, 1999). Therefore, it can be concluded that between the age of 9 and 11 years process of language acquisition is not finished and that children process sentences in an inefficient way due to the differences in brain organization, as suggested by Dorothy Bishop. Similar arguments were offered in the previous paragraph.

Persistence in the inefficient language processing in the SLI group can be inferred from the comparison of two results obtained in this study. First, electrophysiological results show overall lower effects on all experiments, i.e. the difference between conditions are smaller or even non-existent. This means that the children with SLI failed to recognize the errors in the stimulus sentences in the violation condition. The difference actually consisted of a single morpheme (Dative ~ Accusative, Infinitive ~ Participle) and the morpheme is usually only one phoneme (in fact, only infinitive ending consisted of two phonemes, *-ti*). The difference between the experimental conditions was thus, in

Leonard's words, of '*low phonetic substance*' and this makes morphology especially vulnerable in children with SLI (Montgomery & Leonard, 1998). On the other hand, children with SLI showed moderate to good results on phonological discrimination test while their performance on other tests was often poorer. Since all children with SLI included in the study receive therapy, they all have some sort of 'explicit phonological knowledge' and knew how to discriminate between phonemes. When time was not critical, as in this test, the results were good. The children with SLI showed lower results on quick naming, where they had to perform quickly. Together with the electrophysiological tests this indicates processing difficulty, not a representational one.

'Inefficient' processing can also be inferred from broad, weak and long lasting effects (especially noticeable in the late, broad negative deflection in '*case-chi*' experiment and a broad frontal and central negative deflection together with a late and weak P600 effect in '*tense-chi*' experiment). They can indicate different neural substrate, probably not optimal for language processing. However, sentence stimuli, which strained child's attention and comprehension abilities, may perhaps not be optimal choice for establishing processing differences between children with TLD and children with SLI. For example, prefixed words and prefixed pseudowords would perhaps show differences in lexical access and serve as an indicator of even more complex unification processes that go on in sentences, but, at the same time, as a lexical decision task it would be more appropriate experiment for children. In this study sentences were used in order to obtain first comparable data for adults, children and children with SLI.

5.3.4. Confirmation of the hypotheses

Evidence for sentence comprehension. The first group of hypotheses predicts the ERP components that should be obtained in the first group of experiments, i.e. experiments performed on a group of healthy adult speakers (‘*case’, ‘tense’, ‘gender’, ‘quantifier’*). The hypotheses predict LAN-P600 effect in *‘case’* and additional *‘gender*’ experiment due to the structural errors in the violation conditions of the experiments. Since both LAN and P600 were obtained in the experiments, the hypotheses 1.1.1 and 1.2.1 can be fully confirmed.

The hypothesis 1.2.2 predicted N400 effect in the *‘quantifier*’ experiment. Since this component was obtained in the experiment, the hypothesis can be confirmed.

Since no structural violation as in ‘*case*’ experiment was present in the ‘*tense*’ experiment, no LAN was predicted in the H1.1.2. However, a strong negative deflection was observed on the left frontal electrodes starting at around 500 ms and lasting till the end of the epoch. This was not predicted by the hypothesis and was discussed extensively before. The hypothesis 1.1.2 can thus be only partly confirmed.

Sentence comprehension in TLD children and children with SLI. Based on the age of children with TLD a prediction was made stating that there would be no difference between adults and children with TLD because the case and tense systems are acquired at the age of 9-11. However, substantial differences were found. First, overall amplitudes were higher in the TLD group in comparison to adults. Second, no LAN was obtained in the ‘*case-chi*’ experiment and the later latencies of P600 were obtained, as well. In short, hypotheses 2.1.1 and 2.1.2 cannot be confirmed.

Generally, differences between TLD and SLI groups were obtained. However, as the results were somewhat surprising for the TLD group, actual shift in latency for LAN in ‘*case-chi*’ experiment cannot be confirmed due to the fact that LAN was not obtained at all in both groups. However, later latencies of P600 in the SLI group were recorded. The same reasoning should be applied for the results in ‘*tense-chi*’ experiment: later latencies of P600 were indeed obtained, but the late negative deflection was not predicted at all in the first place. Therefore, the hypotheses 2.2.1 and 2.2.2 can be only partially confirmed.

The hypothesis 2.3 predicted the ‘global’ processing deficit in the SLI group, not the deficit on a particular area of grammatical knowledge. Therefore, the hypothesis would have been falsified if the results of SLI children were similar to TLD children in only one experiment. This is not the case: the differences were obtained in both experiments. In addition, the differences between the experiments in the SLI group indicate that the dissociation of the grammatical functions, as observed in adults and – to some extent TLD children – was not obtained in the SLI group. This means that the hypothesis 2.3 can be fully confirmed.

CONCLUSION

Six ERP experiments were performed in order to gain insight into language comprehension in Croatian in three groups of participants: adults, children with TLD and children with SLI. Role and Reference Grammar distinction between *constituent* and *operator* projection of a clause allowed for identification and characterization of the linguistic processes that correspond to the electrophysiological effects obtained in the experiments and enabled generalizations regarding syntactic or semantic nature of the processes. While expectable LAN and P600 effect were obtained in the experiment in which the case of the direct object was manipulated, in the experiment in which the tense of the main verb was violated an unanticipated late negative deflection on the left frontal electrodes was obtained. This late negativity was labeled N400' since it reflects the semantic processes related to the time of the event the sentence is about. The results do not fit into serial models (although one such model, the eADM, is based on RRG), but better fit to the immediacy models in which information is processed as soon as it becomes available no matter whether it is syntactic or semantic in nature. In addition, Croatian data fit into the recent results in sentence comprehension studies in which the syntax-semantics dichotomy is blurred in a way, i.e. syntax related components were obtained where the violation was not syntactic in nature. As in any language with rich morphology, in Croatian case markers carry semantic information about thematic roles; therefore, a grammatical violation triggers electrophysiological response that cannot be simply regarded as 'syntactic'.

Comparisons between adults and children with TLD reveal differences in electrophysiological traces of sentence comprehension. These differences can be related to the different processing of syntactic information in adults and children between 9 and 11. The differences – absence of LAN in case violation, shift in latency for P600 and different (broader) distribution of the late negative wave (N400') when tense of a sentence is violated – can be explained by inefficient language processing of children when developmental processes are still not finished. Maturational processes consist of modularization that corresponds to the strong dissociation between constituent and operator projection processes.

Finally, differences between children with TLD and children with SLI were found. The most prominent difference is a weak electrophysiological effect or absence of difference between experimental conditions and even between experiments. This means, first, that children with SLI at least partly fail to detect grammatical errors and, consequently, achieve sentence comprehension using alternative strategies (perhaps what is usually called '*agrammatical comprehension*'). Second, the differences are explained in terms of impaired, inefficient, limited or slow processing (which is a consequence of slower development), not as a lack of linguistic knowledge. Third, if development is a process that ends in modularization, SLI children definitely lag behind their peers and probably never reach the adult stage developing compensatory strategies instead.

It should be noted that electrophysiological research related to language comprehension is relatively new in Croatian and that the data collected for this study is practically the only usable data for the analysis and discussion of sentence comprehension processes. Therefore, a lot of caution is needed when generalizing from, in fact, a very limited corpus of data. Future work should be oriented toward collecting auditory sentence processing data for which a higher degree of precision and better laboratory conditions are needed. As for the future work in SLI, basic auditory processing data is *condition sine qua non* if electrophysiological methods are to be used as a tool for investigating the causes or background of the language impairments.

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KEY WORDS

Language processing, sentence comprehension, ERP, LAN, P600, N400, N400', adults, children with TLD, children with SLI

BIOGRAPHY

Marijan Palmović was born in 1963, obtained BA in philosophy and linguistics at the Faculty of Philosophy of the University of Zagreb. In 1993 he obtained his MA in logic (*Quine's criticism of modal predicate logic*) at the Faculty of Philosophy in Zagreb - where he was at that time research assistant. In 2001 he started to work in the Laboratory for Psycholinguistic Research, Department of Language and Speech Pathology, Faculty for Special Education and Rehabilitation, University of Zagreb. In 2003 he enrolled the doctoral study *Language Communication and Cognitive Neuroscience* at the University of Zagreb. His interests include language acquisition, language pathology and language processing. He spent study periods at the University of Vienna and Hungarian Academy of Science. Together with his colleague Jelena Kraljević he published a book *Metodologija istraživanja dječjega jezika* (*Methodology of child language research*) in 2006. He takes part in lectures and seminars at the Department of Language and Speech Pathology at the University of Zagreb.

SUMMARY

The method of event-related potentials was used to gain insight in processes related to sentence comprehension in Croatian. Two main designs were used: (1) within-group design aimed at establishing dissociation between two aspects of syntactic processing, as described in Role and Reference Grammar. It is claimed that two projections of a clause in RRG, constituent and operator projection, are cognitively different. This claim was tested in four ERP experiments (*'case', 'tense', 'gender' and 'quantifier'*) with the aim of establishing electrophysiological traces of these *differences*. (2) Between-group design was used to obtain developmental data in a group of children with typical language development and a group of children with Specific Language Impairment. For this purpose two experiments, '*case-chi*' and '*tense-chi*' were conducted on all three groups of participants, adults, children with TLD and children with SLI.

Different patterns of response were obtained in '*case*' and '*tense*' and '*gender*' and '*quantifier*' experiment. In '*case*' and '*gender*' experiments LAN and P600 components were obtained. In '*quantifier*' experiment N400 component was obtained. In '*tense*' experiment strong late negative wave with maximum on left frontal electrodes was recorded. It was labeled N400' due to the semantic nature of the processes it was claimed it represented and due to similar results for processing temporal information obtained in Hungarian. Since grammatical (syntactic) violation was present in all experiments and since two different patterns of ERP were obtained, dissociation between processing constituency and operators is confirmed.

Developmental data on sentence comprehension in Croatian showed that language development can be understood as growing specialization, i.e. modularization of

language function. This followed from broader distributed components with later latencies obtained in both ‘*case-chi*’ and ‘*tense-chi*’ experiments. In the group of children with SLI much smaller differences between experimental conditions (violation – non-violation) were obtained reflecting difficulties of error detection observed in this group of participants. Finally, smaller differences between the experiments could be observed in the SLI group suggesting that the lag in language development consists of lack of modularization of language function. These results are consistent with the hypothesis that the deficit behind SLI is, in fact, processing specific language information by ‘inadequate’ means.

EXTENDED SUMMARY IN CROATIAN

SAŽETAK

Jezično razumijevanje, tj. kako govornici razumiju rečenice svojeg jezika jedno je od najvažnijih pitanja u psiholingvistici. Na to pitanje nastoji se pronaći odgovor u istraživanjima koja se danas razvijaju u tri pravca: prvi (i najstariji) karakterizira formuliranje modela kojim se procesi vezani za jezično razumijevanje nastoje analizirati na sastavne dijelove. Modeli se razlikuju prema tome kako se shvaća tijek procesa vezanih za jezično razumijevanje: odvijaju li se oni jedan iza drugoga, s tim da su izlazni podatci prethodne operacije ulazni podatci za sljedeću, ili se odvijaju paralelno, jedan usporedno s drugim. I za prvu i za drugu vrstu modela (serijski i paralelni) postoje dokazi tako da konačnog odgovora za sada nema.

Drugi pravac proučavanja jezičnoga razumijevanja proizlazi iz modeliranja, ali se temelji na simuliranju procesa pomoću umjetnih neuralnih mreža. Takva istraživanja imaju i praktičnu primjenu u automatskom prepoznavanju i sažimanju teksta, automatskom prevođenju i sl. Međutim, umjetnim neuralnim mrežama mogu se i, prvo, simulirati elementi jezičnog usvajanja i, drugo, kauzalni odnosi vezani za jezično razumijevanje umjetnim 'lezijama'. Glavno je ograničenje ovoga pristupa to što se mogu simulirati samo pojedini dijelovi procesa, a ne proces – na primjer, jezičnoga usvajanja – u cjelini.

Treći pravac istraživanja jezičnog razumijevanja nastoji povezati behavioralne karakteristike s neuralnom podlogom jezične funkcije upotrebljavajući pri tome metode funkcionalnog oslikavanja mozga, metode koje omogućuju promatranje moždane aktivnosti '*on-line*'. U ovome radu upotrijebila se metoda kognitivnih evociranih potencijala koja ima odličnu vremensku rezoluciju (oko 1 ms), ali ograničenja u pogledu lokalizacije aktivnosti u mozgu. Smatra se da je metoda osobito pogodna za istraživanje jezične obrade: odlična vremenska rezolucija pogodna je za istraživanje brzih procesa, a budući da ne zahtijeva svjesnu reakciju na podražaj, pogodna je za istraživanja procesa koji su velikim dijelom automatski ili izvan kontrole govornika. Metoda se sastoji od snimanja signala elektroencefalograma uz istovremeno predočavanje podražaja koji su odabrani prema eksperimentalnim uvjetima. Uprosječivanjem rezultata s obzirom na početak podražaja dobiva se krivulja evociranog potencijala koja predstavlja prosječni moždani odgovor na odgovarajuću klasu podražaja.

Procesi vezani za rečenično razumijevanje ispitivali su se u ovome raduna dvije razine:

(1) kod odraslih govornika hrvatskoga
(2) razvojno – u skupini djece urednoga jezičnog razvoja i u skupini djece s razvojnim jezičnim poremećajem, tj. u skupini djece s posebnim jezičnim teškoćama.

Osnovna je ideja bila disocirati različite vrste rečenične obrade (kod odraslih govornika) i pokazati da se obrada (procesiranje) rečenice razlikuje u djece uredna jezična razvoja i u skupini djece s posebnim jezičnim teškoćama. Disocijacija različitih dijelova gramatike indicija je modularnosti jezične funkcije koja se shvaća kao završni stupanj jezičnoga razvoja budući da modularnost pruža optimalan način obrade velikog broja brzih podražaja. Kod djece će ta modularnost biti manje izražena, a još manje kod djece s razvojnim jezičnim poremećajem. Teorijska podloga te disocijacije jest Gramatika uloga i referenci (GUR). Dva su razloga za to: prvo, jedna je od tvrdnji te teorije ta da se GUR može shvatiti ne samo kao gramatička teorija, nego i kao psiholingvistička teorija, tj.

teorija jezične obrade (razumijevanja i proizvodnje). Drugo, u GUR-u su eksplicitno formulirana predviđanja koja se odnose na jezičnu obradu, a mogu se eksperimentalno provjeriti. GUR razlikuje dvije rečenične '*projekcije*', konstituentsku i operatorsku. Konstituentska projekcija definira temeljne odnose između pojedinih rečeničnih dijelova, glagola, njegovih argumenata i 'periferije' (npr. priloških oznaka). Operatorska projekcija određuje druge gramatičke osobine: ilokucijsku snagu (npr. je li rečenica upitna, niječna ili izjavna), vrijeme ili vid glagolske radnje i sl. (ovisno o jeziku). Jasno se tvrdi da su u smislu jezične obrade procesi vezani za konstituentsku i operatorsku projekciju *kognitivno* različiti. Ako je tako, metoda kognitivnih evociranih potencijala trebala bi pokazati razliku u rečeničnoj obradi onih podataka koji su vezani za konstituentsku i operatorsku projekciju.

U skupini odraslih govornika hrvatskoga provedena su četiri eksperimenta. U svakom eksperimentu manipuliralo se jednom gramatičkom osobinom (prema kojoj je eksperiment nazvan). Eksperiment je odgovarao jednoj od dviju rečeničnih projekcija (prema GUR-u). Tako se u eksperimentu 'padež' manipuliralo padežom izravnog objekta koji je u jednom uvjetu bio ispravan (akuzativ), a u drugom neispravan (dativ) kao u rečenici:

Dječak je u knjižnici pročitao ***knjizi****.*

Eksperiment se sastojao od 100 rečenica s ispravnim i sto rečenica s neispravnim padežom. Budući da padež određuje 'položaj' na konstituentskoj projekciji, pogrješka u padežu odnosi se upravo na konstituentsku projekciju. U drugom eksperimentu manipuliralo se glagolskim vremenom. Eksperiment se sastojao od 100 rečenica s ispravnim i sto rečenica s neispravnim glagolskim vremenom. Pogrješka se sastojala u pogrešnom obliku glavnog glagola: izbor pomoćnog glagola predvidio bi perfekt, ali bi se glavni glagol nalazio u infinitivu kao u sljedećem primjeru:

Brod je sutra sigurno ***zaploviti***.

Tako konstruirane rečenice predstavljaju rečenice s pogrješkom na operatorskoj projekciji.

Dva dodatna eksperimenta zamišljena su radi potvrde te disocijacije na razini nižoj od rečenice, na razini imenske fraze. U eksperimentima se manipuliralo slaganjem roda pridjeva i imenice (npr. *mali kuća* nasuprot *mala kuća*) ili brojivosti (npr. *dva brašna* nasuprot *tri cigle*).

U eksperimentu '*padež*' dobiven je karakterističan elektrofiziološki odgovor koji karakteriziraju dvije komponente kognitivnih evociranih potencijala: lijeva prednja negativnost (eng. *left anterior negativity – LAN*) i kasni pozitivni pomak P600. Taj karakterističan valni oblik dobiven je u brojnim eksperimentima u kojima se u raznim jezicima manipuliralo nekom gramatičkom osobinom, najčešće nekom vrstom sročnosti. U eksperimentu '*vrijeme*' dobiven je neočekivan rezultat. LAN je izostao (kao što je bilo predviđeno budući da u rečenici nije bilo strukturne pogrješke koja, karakteristično, elicitira LAN). Zabilježen je, međutim, kasni negativni val latencije od 500 ms do kraja epohe, najjače izražen na lijevim prednjim elektrodama. Sličan je valni oblik zabilježen i u mađarskom u rečenicama u kojima se manipuliralo vremenskim prilogom (npr. *jučer* umjesto *sutra*). Budući da se radi o pogrješci koja čini nejasnim dio značenja rečenice (kad se događa radnja), taj se valni oblik nazvao N400' (prema N400 koji je zabilježen u brojnim eksperimentima u kojima se manipuliralo ovim ili onim aspektom značenja). U eksperimentu '*rod*' dobiven je karakterističan odgovor LAN-P600, dok je u eksperimentu '*brojivosti*' dobiven N400, tj. negativan središnje distribuiran val s vrškom na oko 400 ms od podražaja.

Budući da su u različitim eksperimentima dobiveni različiti elektrofiziološki odgovori, može se potvrditi disocijacija gramatičkih funkcija, dok grupiranje sličnih rezultata omogućuje njihovu interpretaciju koja je velikim dijelom konzistentna s gramatikom uloga i referenci. Naime, sličan odgovor u eksperimentima '*padež*' i '*rod*' s jedne strane i *'vrijeme'* i *'brojivost'* s druge omogućuju važnu generalizaciju: na sličan se način obrađuju podatci koji pripadaju konstituentskoj projekciji, a na drugačiji se način obrađuju podatci koji pripadaju operatorskoj projekciji. Ti rezultati potvrđuju tvrdnju prema kojoj se Gramatika uloga i referenci može shvaćati kao psiholingvistički model, tj. kao model jezičnoga razumijevanja (i proizvodnje). S druge strane, kasni negativni val dobiven u eksperimentu '*vrijeme*', sličan rezultatima dobivenima manipuliranjem vremenskog priloga u mađarskom, a u ovome radu sličan komponenti N400 dobivenoj u eksperimentu '*brojivost*' ukazuje na to da se radi o obradi dijela *značenja* rečenice. Kao što se elementi konstituentske projekcije preslikavaju na makrouloge (dakle, semantičke kategorije), predlaže se da se elementi operatorske projekcije preslikavaju na skup relacija definiran različitim sustavima filozofske logike: epistemičke, temporalne, modalne i sl., ovisno o operatorima specifičnima za pojedini jezik.

Rezultati dobiveni na skupini od devetoro djece uredna jezičnoga razvoja pokazuju sličnost s rezultatima dobivenima na skupini odraslih govornika. Ipak, mogu se zabilježiti kasnije latencije komponenti ili čak odsustvo pojedinih komponenti. Uz to, distribucija pojedinih komponenti kod djece uredna jezičnoga razvoja šira je nego kod odraslih govornika. U ovome radu takva šira distribucija osobito je izražena u eksperimentu '*vrijeme*' gdje se može uočiti široka bilateralna distribucija kasnog negativnog vala koji je u odraslih govornika ograničen na lijevu hemisferu, i to samo anteriorno.

Treću skupinu ispitanika činila su djeca s posebnim jezičnim teškoćama. U ovome radu testovnim materijalom najvećim dijelom razvijenom u Kliničko-istraživačkom odjelu Laboratorija za psiholingvistička istraživanja izdvojena je skupina od četvero djece s posebnim jezičnim teškoćama. Njihovi rezultati na dva eksperimenta, '*padež*' i '*vrijeme*', razlikuju se od rezultata dobivenim na grupi djece uredna jezičnoga razvoja. Prvo, dobivene komponente pokazuju kasnije latencije i još širu distribuciju od one dobivene na skupini djece uredna jezičnoga razvoja. Drugo, razlika između eksperimentalnih uvjeta u oba eksperimenta gotovo da ne postoji. To se može tumačiti nemogućnošću (tj. slabijom sposobnošću) djece s posebnim jezičnim teškoćama da otkriju pogrješku u rečenici. Treće, vrlo je slabo izražena razlika između eksperimenata u ovoj skupini ispitanika. Taj je rezultat osobito zanimljiv u svjetlu disocijacije koja se može uočiti na razini obrade jezičnih podataka konstituentske i operatorske projekcije kod odraslih govornika i, u manjoj mjeri, kod djece uredna jezičnoga razvoja. Taj rezultat ukazuje na modularnost jezične funkcije, ne samo na razini jezične funkcije u cjelini, nego na razini pojedinih aspekata jezične obrade, prema modelu temeljenom na Gramatici uloga i referenci. Modularnost se, s druge strane, može shvatiti kao konačan cilj jezičnoga razvoja; modularnost garantira optimalan način obrade jezičnih podataka, brzinu i automatizam. Kod djece uredna jezičnoga razvoja u dobi između 9 i 11 godina taj cilj još nije postignut ali je "na vidiku". Kod djece s posebnim jezičnim teškoćama te modularnosti nema. Nedostatak modularnosti u jezičnoj obradi uzrokuje to da govornik obrađuje jezične podatke na "neprimjeren" način, tj. na način koji nije optimalan za obradu jezičnih podataka. Na taj se način mogu protumačiti behavioralni podatci karakteristični za PJT: slabu sposobnost otkrivanja pogrješke, slabosti u obradi onih podataka kod kojih je brzina bitan čimbenik (slab rezultat upravo na tim testovima karakterističan je za skupinu ispitanika s PJT u ovome radu).

Rezultati dobiveni na eksperimentima '*padež*' i '*vrijeme*' mogu doprinijeti raspravi o uzrocima ili "pravoj prirodi" posebnih jezičnih teškoća. Oni govore protiv onog shvaćanja PJT koje taj razvojni poremećaj shvaća kao nedostatak ovog ili onog aspekta jezičnoga znanja (bilo da se radi o produženom razdoblju opcionalnog infinitiva, nedostatku pravila pomicanja ili nedostatku pravila dodjeljivanja tematskih uloga) budući da se kod djece s PJT nije otkrila razlika u odnosu na djecu uredna jezična razvoja samo na jednom od dvaju eksperimenata. Nasuprot tomu, PJT se može promatrati kao opći deficit u obradi informacija pri čemu se razvojna komponenta tog poremećaja vidi u nemogućnosti postizanja modularnosti kao optimalnog načina obrade brzog tijeka podataka, što je karakteristično za jezik. Modularnost se, dakle, ne shvaća kao nešto što je unaprijed zadano, tj. urođeno, nego nešto što se postiže (ili ne postiže) razvojem. Takva je slika PJT u skladu s onime što je poznato o jezičnoj obradi iz drugih područja kognitivne neuroznanosti jezika: na primjer, iz područja umjetnih neuralnih mreža ili razvojne neuroznanosti (rast i gubitak sinaptičkih veza u ranoj dobi) i, prema tome, može predstavljati dobru osnovu za daljnja interdisciplinarna istraživanja.