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Neurocognitive mechanisms of morphosyntactic information processing: Multimodal investigations

Dissertation summary for the purpose of obtaining academic degree Doctor of Philosophy in Cognitive sciences

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3. 60th Psychonomic Society Conference 14-17 November 2019 (Montreal, Canada). Report: *(Morpho)Syntactic Priming as a Mechanism for Rapid Automatic Syntax Parsing: ERP Evidence.*
4. 25th Architecture and Mechanisms of Language Processing, 6-8 September 2019, (National Research University Higher School of Economics, Moscow, Russia). Report: *Syntactic priming and extralinguistic information contribute to rapid automatic syntax parsing: ERP evidence.*

Introduction

Relevance of the topic

In spite of extensive research, language faculty is one of the least understood functions of the human brain. Therefore, language-cognition interface remains a central question of a long-standing debate about the nature of linguistic processing (Jackendoff, 2003). This general research agenda translates into more specific research questions. One of such questions concerns the degree of functional and neuroanatomical interplay between language and general cognitive processes, such as memory or attentional control. Another important and related question is the interplay between processing linguistic information *per se* and different extralinguistic speaker-related features, for example gender (Knösche et al., 2002).

Human language is characterized by a rich system of syntactic/grammatical rules that govern the combinatorial use of constituent elements. It was demonstrated that the neurocognitive system underlying (morpho)syntactic processing is relatively independent of other cognitive systems, having a high degree of automaticity (Hahne & Friederici, 1999; Pinker, 2003; Pulvermüller et al., 2008). Research has shown, for example, that morphosyntactic processing can still be successfully accomplished by the brain even if the attention is diverted away from the linguistic input. It is true at least for English (Pulvermüller et al., 2008), Finnish (Shtyrov et al., 2003), and French (Hanna et al., 2014). Recently, similar research has been conducted using Russian (Alekseeva et al., 2024) further extending a largely universal nature of this phenomenon.

Commencing arguably before the non-automatic (top-down controlled) processes of parsing lexico-semantic information and combining overall sentence information including morphology, semantics and syntax, morphosyntactic processing is believed to include an automatic level as well as a further attention-dependent one (Friederici, 2002). The former type of processing takes place independently of focused attention. Experimentally, this can be probed using a special passive non-attend paradigm. Moreover, by employing carefully selected and controlled specific language materials, this paradigm could be used to acquire novel knowledge about particular morphological components and their processing inside as well as outside the language system. One such example is the processing of voice-specific parameters that can interact with the language's grammatical system and can be modulated by morphology.

In my PhD research, I take early morphosyntactic processing as the starting point in order to examine two key processing levels within the morphosyntactic field: (1) the extralinguistic level where the processing of the morphosyntactic gender information is based on the speaker's voice features, and (2) the linguistic level, where the processing is based on the presence of specific morphological components – inflectional affixes. The latter level focuses on the investigation of a specific morphological component – the so-called zero morpheme. Both of these levels provide useful insights into morphosyntactic word processing. On the one hand, in my research I examine the potential inclusion of additional extralinguistic information. On the other hand, I explore a particularly controversial (both linguistically and cognitively) type of a null constituent - the zero morpheme, whose neurocognitive correlates are still poorly understood.

Well-grounded research foundations and research questions

Automatic morphosyntactic processing and general methodology

The temporal dynamics of written and spoken language comprehension has been typically explored using techniques such as electroencephalography (EEG) and magnetoencephalography (MEG), thus making it possible to extract important neurocognitive information regarding specific neurolinguistic processes with a highly precise temporal and spatial resolution. These methods have allowed to isolate distinct components of event-related potentials (ERPs in EEG) or fields (ERFs in MEG) that could be associated with different stages of (morpho)syntactic processing. Of these, the most studied ERP/ERF components are the Early Left-Anterior Negativity or ELAN (Neville et al., 1991), the Left Anterior Negativity or LAN (Friederici et al., 1993), and P600, a later positive shift (Osterhout & Holcomb, 1992). Besides the timing information, the use of EEG/MEG topographic and source analyses capabilities can provide relevant information regarding the cortical structures involved.

The first stage of this processing is known to be accompanied by the ELAN component with a peak around 120-200 ms after the critical event onset (e.g., a grammatical/syntactic/morphosyntactic violation). It owes its name to its comparably early latency and a left frontal distribution (Friederici et al., 1993; Hahne & Friederici, 1999; Neville et al., 1991), although it has also been found to be elicited bilaterally (Hahne & Jescheniak, 2001; Knösche et al., 1999). Usually, it is related to syntactic violations during early and automatic analysis of word and sentence composition. For example, Friederici and colleagues showed that ELAN is closely related to phrase structure errors (Friederici, 1995; Friederici et al., 1993). Such errors can be seen during a mismatch/disagreement between the words in a phrase (for example, **Der Freund wurde im hesucht/The friend was in the visited*; Friederici et al., 1993). Such violations make it impossible to build a felicitous local phrase structure.

Others, however, have suggested that the ELAN effect may be an artifact (Steinhauer & Drury, 2012), as its onset is relatively early and may not be related to morphosyntactic processing *per se*. For example, lexical access has been argued to take at least ~200 ms to commence (Allopenna et al., 1998; Sereno & Rayner, 2003); hence it is problematic to clearly specify the nature of morphosyntactic processes preceding it. At the same time, several studies have shown that lexical and semantic processing can indeed start much earlier and can even take place without focussed attention on the linguistic input (Pulvermüller & Shtyrov, 2006), suggesting a high degree of automaticity of early language processing. One explanation for this rapid and automatic activation suggests that language comprehension system in essence *predicts* possible incoming elements (including morphosyntactic ones) as early as possible based on the characteristics of previously encountered sentences (Fonteneau, 2013), which may explain the very early onset of the ELAN. These predictions could be related to the basic morphosyntactic processes, which start with the preprocessing of the syntactic structure and continue with semantic information processing (Friederici, 2002; Friederici & Weissenborn, 2007).

Later morphosyntactic components do not correspond to purely automatic processes and can be linked to additional top-down attention-related stages of comprehension and a range of other processes, potentially running in parallel/cascade fashion with the automatic ones. I will therefore discuss them only briefly. The second stage of morphosyntactic processing is revealed in the LAN component, which lasts approximately from 300 ms to 500 ms and has a similar left anterior distribution. Whilst having a certain degree of automaticity (Gunter et al., 1997, 2000), it is still largely connected to the more controlled processing stages. For example, the LAN is usually referred to the morphosyntactic difficulties within the overall sentence structure (Friederici, 1995; Molinaro et al., 2015; Osterhout & Mobley, 1995) as well as to the detection of phrase-agreement violations (Barber & Carreiras, 2005; Bornkessel & Schlesewsky, 2006). The arguably final processing stage is reflected by the P600 complex. This is a later (after 500 ms) positive shift whose maximum amplitudes are registered over the posterior scalp regions in EEG. It is linked to the global-level syntactic integration, reanalysis, and repair (Friederici, 2002; Hagoort et al., 1993; Kaan & Swaab, 2003; Osterhout & Mobley, 1995).

Considering a largely predictive nature of syntactic dependencies, parsing of phrases, and morphological decomposition, it is important to use a paradigm that could address the automatic aspects of morphosyntactic processing both within and without the language system. Here, I implemented the protocol of passive auditory presentation typically used in language studies where auditorily presented experimental stimuli are accompanied by a concurrent visual task, to which participants are instructed to pay attention while ignoring the auditory linguistic input (for example, morphosyntactic study by (Hasting et al., 2007).

In line with the typical ERP approach, I used a counterbalanced design whereby the same gender-marked verbs appeared in syntactically or extralinguistically correct and incorrect pronoun-verb phrases using an inflectionally rich language – Russian. Crucially, I also included a further, context-free condition – comprising the same gender-marked verbforms but without the preceding subject that could pre-activate the gender feature. This approach capitalises on a *morphosyntactic priming* theory (Oltra-Massuet et al., 2017), according to which there is a priming element in the phrase processing that pre-activates (i.e., primes) the processing of the next word's morphosyntactic features. More specifically, it was demonstrated that the construction of a pre-processed grammatical template based on a certain pronoun feature (here, gender) enhances activation of the ELAN component (Hasting et al., 2007; Leminen et al., 2013; Pulvermüller et al., 2008; Pulvermüller & Shtyrov, 2003, 2006). This methodological design could address research questions related to the following two levels of morphosyntactic processing: (1) the processing of morphosyntactic gender information extracted from the speaker's voice, and (2) putative existence and activation of zero morpheme representations in the brain.

Research Question 1

Within Research Question 1 (Alekseeva et al., 2022a), I investigated how and when linguistic and extralinguistic gender information is integrated during sentence processing. The speaker's voice provides reliable and quick information that supports sentence comprehension (Knösche et al., 2002). For example, the speaker's apparent gender can be recognized from their voice (Apicella & Feinberg, 2009; Hodges-Simeon et al., 2011; Junger et al., 2013; Li et al., 2014; Mullennix et al., 1995; van Dommelen & Moxness, 1995). Furthermore, many languages mark the grammatical gender explicitly, adding another source of gender information and further complicating the interaction between the speaker's gender and the grammatical gender of a given language constituent. Moreover, sentence comprehension takes into account both the listener's gender and that of the speaker (Junger et al., 2013). A specific voice-gender effect has been documented in ERPs as an early (at around 150–250 ms) increase of the amplitude when hearing the opposite gender voices, compared to gender-matched stimuli (Casado & Brunellière, 2016).

Other ERP studies have shown the modulation of the N400 and/or P600 components related to the inconsistencies between the semantic meaning and the speaker's representation (Bornkessel-Schlesewsky et al., 2013; Lattner & Friederici, 2003; Van Berkum et al., 2008). While the P600 component, previously shown to be of predominantly syntactic nature, typically accompanies the violations of the stereotypical role nouns, the semantically related N400 may result from semantic-pragmatic incongruences that occur when the listener encounters words/phrases that are not semantically felicitous given the speaker's apparent identity. Given the sparsity of these findings and the lack of compatibility between them, the questions of how and when the speaker's gender information is integrated by the listener's language system during the comprehension process remain largely unanswered.

Taking together the timing of early morphosyntactic processing discussed in the introduction and the findings of early speaker-listener gender interaction suggested by some of the previous ERP studies mentioned above, I hypothesized that it could be the case that these are simultaneous processes that are parallel in nature and/or tightly integrated.

Research question 2

My Research Question 2 (Алексеева и др., 2022b; Alekseeva et al., 2022c) refers to one of the most problematic issues in language processing – the disconnect between theoretical linguistic frameworks and their putative neurobiological correlates. Linguists often use highly abstract and derived models that include abstract constituents and theoretical constructs largely without any evidence of their neurocognitive basis. One of such elements is the so-called “null constituent” – that is, one without any overt graphemic or phonological representation (Bally, 1932). As a category, it includes sentential constituents with semantics (or pragmatics) like ellipsis, wh- and np-movements, which were showed to have neurocognitive representations (see Carlson & Harris, 2018; Sekerina et al., 2019; Лауринавичюте et al., 2015). However, the most problematic element in this abstract category is the zero morpheme, which does not have any semantics but projects only a rather abstract syntactic function (for example, verbal number agreement: *they give-Ø*$_{PL}$*, he give-s*$_{SG}$). Due to the lack of any overt representation, there is a significant controversy around zero morpheme’s nature and its neurocognitive reality – in terms of individual languages and universalist theories of grammar.

Any study of the zero morpheme is complicated by several pitfalls. First, it is the inability to separate zero-morpheme processing from other morphological units and thus document unequivocal evidence of zero-morpheme syntactic function (as opposed to simply detecting the absence of graphemically or phonologically represented element; Fodor, 2013). In addition, a controversial logic of including the zero in grammar as a morpheme makes it difficult to operationalize it (see main linguistic theories that tackled the zero-morpheme problem: Anderson, 1992; Aronoff, 1993; Beard, 1995; Chomsky, 2014; Halle et al., 1993; Oltra Massuet, 1999; Wunderlich & Fabri, 1995).

Also, the issues of processing and storing of zero morphemes remain unclear. On the one hand, a zero-marked form (e.g. “*cat-**Ø***$_{SG}$”) can be stored as a whole (see full-form storage and dual-system approaches in Bybee, 1995 and Pinker, 2015). This entails the inability to separate zeroes from the rest of the morphemes presented in the wordform overtly. On the other hand, any evidence of decomposition taking place would reflect its neurocognitive representation as a distinct morpheme (see decomposition approach in Taft, 2004).

The limited existing literature on the topic diverges in the results and their interpretations. For example, Vasilyeva (2016), using a visual lexical decision task, found shorter reaction times for zero-marked forms compared to the overt ones, while Gor and colleagues (2017), using the same task in the auditory modality, did not find any significant differences in reaction times for these two types of inflectional morphemes. At the brain level, wordforms with zero morphemes were studied using functional magnetic resonance imaging (fMRI) using language production with a visual lexical decision task (Sahin et al., 2006). These authors found significant activation in Broca's area for zero morpheme processing and interpreted it as evidence of its neurocognitive reality.

Put together, these inconclusive and fragmented results do not provide sufficient evidence of zero-morpheme processing. Faster reaction times for zeroes can in fact be argued to be the evidence of the whole-form storage and thus no zero-morpheme processing. In turn, similar reaction times for zero and overt morphemes can stem from decomposition for both types of morphemes, similar processing routes or just and equal time for parsing overt morphemes and gaps in the input stream. Moreover, behavioral tasks (such as lexical decision task) and fMRI do not address neural processes directly, and do not provide fine-grain time resolution accurate enough to address the level of highly automatic early morphological processing in the highly transient process of language comprehension and, therefore, may not be sensitive enough to disentangle the processing of zero morphemes from the neighboring units (most importantly, word stem).

The use of EEG, on the other hand, offers excellent temporal resolution for tracking linguistic processes. Furthermore, a passive non-attended approach to recording brain responses allows to focus on attention-independent processing stages/types, allowing to estimate putative automatic morphosyntactic processes. In addition, a grammaticality paradigm conventionally applied in neurolinguistic ERP research, which involves counterbalanced presentation of grammatically/morphosyntactically felicitous and incongruent combinations of words/morphemes, allows to manipulate not as much the zero morpheme as a covert form *per se* but rather its syntactic function while successfully controlling for several variables.

To make use of this approach, I operationalized zero-morpheme constituent in a gender agreement paradigm and investigated its ability to be predicted or primed by specific linguistic information, tested through a specific ERP component (i.e., ELAN), whose patterns I argue could offer direct evidence of its processing. According to the pre-activation or predictive coding accounts (Friston, 2005), a reduction in the corresponding ERP's amplitude during the inflectional morpheme's presentation should be observed when an overt gender marker (for example, feminine in Russian) is pre-activated by the preceding feminine pronoun (Fonteneau, 2013; Pulvermüller & Shtyrov, 2003; Shtyrov et al., 2003), whereas a fully-fledged morpheme activation is expected in the absence of such a pre-activation resulting in a larger response by comparison.

Novelty of the present research

Main theoretical novelty

Our research provides a better understanding of morphosyntactic processing of morphological units. It also goes beyond the level of morphology and language itself – by considering more abstract categories as speaker-related information, i.e., voice-based gender characteristics. Thus, Research Question 1 provides insight into the temporal order of the linguistic and extralinguistic information processing, and it also allows us to consider it in a non-linear way. Research Question 2 helps gain a better understanding of the zero-morpheme nature by looking at it from a variety of angles, but also to demonstrate its existence at the neurocognitive level. In addition, this study serves as a foundation for future research into zero morphemes, which can be extended to other cases both in Russian and in other languages as well as to other types of null constituents.

Main methodological and practical novelty

- The present passive auditory presentation protocol with counterbalanced presentation of (in)congruent pronoun-verb phrases, combined with EEG recording, allows to examine the mechanisms involved in the integration of speaker's extralinguistic (here, gender) information into the neurolinguistic processing, as well as to provide direct evidence of the reality of specific linguistic elements (such as zero morpheme) in a timely-precise manner.
- The obtained findings regarding the automaticity and earliness of speaker-specific information carried by voice properties into language comprehension is not only useful for the understanding of the unfolding of these processes at neural level, but it may also have implications for the educational purposes in relation to learning both native and second language.
- The outputs of the zero-morpheme research can be used for recommendations for developing language grammar materials for educational purposes with objective explanation of the zero-morpheme basis and usage.

- The EEG/MEG protocol with passive auditory presentation with visual distraction and eye-tracking morphosyntactic priming protocol can be used to investigate the level of automaticity of morphosyntactic processing in L2 Russian learners. Furthermore, it can serve as one of the assessment tools in language proficiency tests for learners of Russian as a foreign language as well as to be expanded to other inflectionally rich languages. Building the bridge between fundamental and applied sciences – integrating objective experimental approaches from psychology and neuroscience into the study of fundamental issues in linguistics (or, potentially, other sciences and humanities) provides the opportunity to address a range of cross-disciplinary gaps in neurocognitive and neurolinguistic knowledge and related fields.

The degree-seeking candidate's personal participation in obtaining the outcomes stated in the dissertation

Research Question 1: Setting the research problem, reviewing the literature, developing the paradigm, writing the code for stimulus presentation, collecting, processing, and analysing the data, interpreting the results, drafting, and finalizing the manuscript.

Research Question 2: Setting the research problem, reviewing the literature, developing the paradigm, writing the code for stimulus presentation, collecting, processing, and analysing the data, interpreting the results, drafting, and finalizing the manuscripts.

Conclusion

My PhD research constitutes an important step towards a better understanding of the brain mechanisms of language comprehension. Its key contributions to the field are in revealing new aspects of extralinguistic information processing and its integration with the linguistic information, and in addressing the nature of the so-called zero morpheme, a long-debated theoretical construct in linguistics, whose reality in the brain has avoided detection until now. First, our findings provide valuable evidence regarding the timescale of language comprehension, particularly regarding the integration of the voice features with morphosyntactic processing. Second, the novel experimental protocol used in my research allows to experimentally address the zero-morpheme problem from a different perspective and collect direct evidence of its neurocognitive nature as well its early automatic processing signatures at the very first steps of morphosyntactic analysis. Future research including the protocols proposed in this work will be able to investigate neurobiological and behavioral signatures of zero morpheme and verify the uniqueness or universality of zero-morpheme functioning and representation within and across languages.

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