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An ER-fMRI study of Russian inflectional morphology

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ABSTRACT

The generation of regular and irregular past tense verbs has long been a testing ground for different models of inflection in the mental lexicon. Behavioral studies examined a variety of languages, but neuroimaging studies rely almost exclusively on English and German data. In our fMRI experiment, participants inflected Russian verbs and nouns of different types and corresponding nonce stimuli. Irregular real and nonce verbs activated inferior frontal and inferior parietal regions more than regular verbs did, while no areas were more activated in the opposite comparison. We explain this activation pattern by increasing processing load: a parametric contrast revealed that these regions are also more activated for nonce stimuli compared to real stimuli. A very similar pattern is found for nouns. Unlike most previously obtained results, our findings are more readily compatible with the single-system approach to inflection, which does not postulate a categorical difference between regular and irregular forms.

1. Introduction

Inflectional morphology is at the center of an important debate in cognitive science, concerning the general principles according to which the mental lexicon is organized. So-called "Dual-system" (DS) approach distinguishes regular and irregular morphological forms. The former are computed by rules, the latter are stored in the memory. In the alternative "Single-system" (SS) approach, all forms are generated and processed by a single integrated system.

Initially, English past tense morphology was the testing ground for both approaches. According to the "Words and Rules" model, a version of DS approach proposed by Pinker (1991, 1999), regular past tense forms are generated and processed by a symbolic rule that is part of the productive, combinatorial system of grammar. Irregular forms are learned by rote and stored in the lexicon, from where they can be retrieved through associative memory mechanisms. The DS approach was also advocated e.g. in (Marslen-Wilson & Tyler, 1997; Pinker & Prince, 1988; Ullman, 2004). On the contrary, a connectionist network model from (Rumelhart & McClelland, 1986) represents a single system without any symbolic rules. All past tense forms are generated and processed by associative mechanisms that take into account phonological similarity and token and type frequencies of different elements. The SS approach was further developed e.g. in (MacWhinney & Leinbach, 1991; McClelland & Patterson, 2002; Plunkett & Marchman, 1993). The range of data used to test SS and DS theories has been very diverse: behavioral and neurophysiological experiments where participants generated forms from various real and nonce verbs, language acquisition and language deficit studies, and computer simulations. The results have always been controversial.

However, English past tense morphology is exceptionally simple: there is only one productive class that includes the vast majority of verbs and a small number of irregular verbs. So various authors investigated verb and noun inflection in other languages where the situation is more complex. German, Icelandic, Norwegian, Italian, Spanish, Arabic and Hebrew were among them (e.g. Berent, Pinker, & Shimron, 1999; Clahsen, 1999; Clahsen, Aveledo, & Roca, 2002; Hahn & Nakisa, 2000; Orsolini, Fanari, & Bowles, 1998; Orsolini & Marslen-Wilson, 1997; Plunkett & Nakisa, 1997; Ragnasdóttir, Simonsen, & Plunkett, 1999). Studies on Russian are discussed in Section 1.3. The findings offered new challenges for both approaches, and some of them cannot be easily accounted for by either approach. We illustrate this on the example of Russian below.

Thus, widening the pool of languages was extremely important for the SS vs. DS debate. For this reason, it appears to be

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problematic that existing functional imaging studies of past tense generation rely only on English, German and, in one case, Spanish data (Beretta et al., 2003; de Diego-Balaguer et al., 2006; Desai, Conant, Waldron, & Binder, 2006; Dhond, Marinkovic, Dale, Witzel, & Halgren, 2003; Indefrey et al., 1997; Jaeger et al., 1996; Joanisse & Seidenberg, 2005; Oh, Tan, Ng, Berne, & Graham, 2011; Sach, Seitz, & Indefrey, 2004; Sahin, Pinker, & Halgren, 2006; Ullman, Bergida, & O'Craven, 1997a). In most studies, irregulars are associated with a larger number of activated regions, but the list of these regions, as well as proposed explanations differ greatly. There are also several electrophysiological studies dedicated to past tense formation in English and German (e.g. Lavric, Pizzagalli, Forstmeier, & Rippon, 2001; Marslen-Wilson & Tyler, 1998; Münte, Say, Clahsen, Schiltz, & Kutas, 1999; Newman, Izvorski, Davis, Neville, & Ullman, 1999; Newman, Ullman, Pancheva, Waligura, & Neville, 2007), which show variable results.

The present paper aims to fill this gap. We conducted an fMRI study based on Russian language where participants were asked to generate present tense forms from different real and nonce (nonword) verbs and to pluralize real and nonce nouns. We tried to avoid numerous pitfalls identified by the critics of the previous studies. We used two tasks (inflecting verbs and nouns) in a random order, which minimizes the risk of priming and strategy effects, and large sets of stimuli matched for word frequency and phonological complexity.

1.1. A brief description of the Russian verb system

Russian verbs have two stems: the present/future tense stem and the past tense stem. Correlation between them determines the verb class. Out of several existing approaches, we will rely on the one developed by Jakobson and his followers (Davidson, Gor, & Lekic, 1996; Jakobson, 1948; Townsend, 1975), according to which Russian has 11 verb classes and several so-called anomalous verbs. Ten classes are identified by their suffixes (verbal classifiers). The eleventh class has a zero suffix, and is subdivided into subclasses depending on the quality of the root-final consonant (Jakobson and Townsend counted them as 13 separate classes). It includes many conjugational patterns and contains well under 100 basic stems.

Conjugational patterns of different classes include truncations or additions of the final consonant or vowel and may also include stress shifts, suffix alternations, alternations of stem vowels and stem-final consonants. Russian has two conjugation types in the present and future tense, i.e. two different sets of endings, and to which one a verb belongs is determined by its class. Importantly, the verb class is often unrecoverable from a particular form of the verb. For example, *čitát'* 'to read' belongs to the AJ class, and its 3Pl present tense form is *čitá-j-ut* (*-j-* suffix is added, first conjugation type). *Pisát'* 'to write' belongs to the A class, and its 3Pl present tense form is *píš-ut* (*-a-* suffix is truncated, first conjugation type, final consonant alternation, stress shift). *Drožát'* 'to tremble' belongs to the ZHA class, and its 3Pl present tense form is *drož-át* (*-a-* suffix is truncated, second conjugation type).

Thus, Russian verb system is very complex. And, crucially, there is no obvious division into regular and irregular verbs. Unlike in English, there is no single productive pattern that can be applied to any stem irrespective of its phonological characteristics. Five verb classes are productive, but dramatically differ in type frequency. *The Grammatical Dictionary of the Russian Language* (Zaliznyak, 1977) contains 27,409 verbs. We counted the number of verbs in these five classes: 11,735 in the AJ class, 6875 in the I class, 2815 in the OVA class, 1377 in the NU class and 638 in the EJ class.

1.2. A brief description of the Russian noun system

Russian noun system is much less complex than Russian verb system. Nouns are inflected for number and case and are classified into different declensions depending on their gender and on the set of their number and case endings. There are three main declensions, the forth declension with adjectival endings, several exceptional nouns and a number of uninflected nouns. First and second declensions usually have a choice of two endings for a particular form depending on the last consonant of the stem (all stems in the third declension end in palatal or sibilant consonants and use one set of endings). In addition to that, inside every declension there are small groups of nouns with various irregularities: minor stem changes or unusual endings in some forms. The majority of Russian nouns do not change their stem.

Some endings are unique for a particular declension, but most of them are shared by two or even three main declensions. In particular, Nom.Pl forms, which we looked at in this study, can have the following endings: *–i* (used with palatal, sibilant and velar stems of masculine and feminine nouns in all three declensions), *–y* (used with the other stems of masculine and feminine nouns in the first and second declension), *–ja* (used with palatal, sibilant and velar stems of neuter and some masculine nouns in the first declension), *–a* (used with the other stems of neuter and some masculine nouns in the first declension), *–e* (used in a very small group of animate masculine nouns in the first declension).

1.3. Previous studies testing the SS and DS approaches on Russian

The predictions of the SS and DS theories were tested in numerous experiments with Russian verbs (e.g. Chernigovskaya, Tkachenko, Dalbi, & Svistunova, 2007; Gor, 2003, 2010; Gor & Chernigovskaya, 2001; Gor & Chernigovskaya, 2003; Gor & Chernigovskaya, 2005; Gor & Jackson, 2013; Gor, Svistunova, Petrova, Khrakovskaya, & Chernigovskaya, 2009; Svistunova, 2008; Tkachenko & Chernigovskaya, 2010). Adult native speakers, L1 and L2 learners and subjects with various neurological and developmental deficits were examined. In the majority of these experiments, participants were provided with infinitives or past tense forms of real or nonce verbs and prompted to generate 1Sg and 3Pl present tense forms.

Healthy adult native speakers showed a strong tendency to overgeneralize the AJ class pattern (AJ class is the most frequent). In particular, they applied it to the nonce verbs ending in *–ili* (only two real verbs and their derivates have this conjugational pattern, all the others belong to the productive and highly frequent I class) and to the ones ending in *–yli* (no real verbs have this conjugational pattern). Thus, despite the fact that Russian has several productive and highly frequent classes, one conjugational pattern is used as the default one. This is in conflict with the SS theory.

Four-year-old children also heavily rely on the AJ class pattern. But gradually, other patterns become more active. For example, around the age of five children stop making mistakes with OVA class verbs and actively overgeneralize this pattern. Overgeneralizations that do not respect phonological properties of the stem are a hallmark of a rule in the DS approach, and several rules that have different potential to be overgeneralized depending on various frequency-related and phonological factors contradict its very essence. The generalizations made in the studies of English-speaking subjects with SLI (specific language impairment), aphasiac deficits and Alzheimer disease (e.g. Ullman et al., 1997b) that supported the DS approach also were not borne out in Russian. The group of authors working on Russian argues that Yang's (2002) model relying on multiple rules of different status may be better suited to account for their findings. A similar model for Russian is developed in (Gor, 2003).