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Neurocognitive dimensions of lexical complexity in Polish

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ABSTRACT

Neuroimaging studies of English suggest that speech comprehension engages two interdependent systems: a bilateral fronto-temporal network responsible for general perceptual and cognitive processing, and a specialised left-lateralised network supporting specifically linguistic processing. Using fMRI we test this hypothesis in Polish, a Slavic language with rich and diverse morphology. We manipulated general perceptual complexity (presence or absence of an onset-embedded stem, e.g. *kotlet* 'cutlet' vs. *kot* 'cat') and specifically linguistic complexity (presence of an inflectional affix, e.g. *dom* 'house, Nom' vs. *dom-u* 'house, Gen'). Non-linguistic complexity activated a bilateral network, as in English, but we found no differences between inflected and uninflected nouns. Instead, all types of words activated left inferior frontal areas, suggesting that all Polish words can be considered linguistically 'complex' in processing terms. The results support a dual network hypothesis, but highlight differences between languages like English and Polish, and underline the importance of cross-linguistic comparisons.

1. Introduction

A critical issue in the study of language as a neurocognitive system has been the role of the left hemisphere, and specifically the left inferior frontal gyrus (LIFG), in the processing of morphology and syntax. Damage to these regions usually leads to significant disruption of language function, while damage to parallel areas in the right hemisphere does not (Goodglass, Christiansen, & Gallagher, 1993). Neuroimaging evidence confirms the importance of these parts of the brain for language processing, and points to a core decompositional network centred on the LIFG (Binder et al., 1997, 2000; Embick, Marantz, Miyashita, O'Neil, & Sakai, 2000; Friederici, Rüschemeyer, Hahne, & Fiebach, 2003; Hagoort, 2005; Marslen-Wilson, & Tyler, 2007; Musso et al., 2003; Tyler et al., 2011; Vigneau et al., 2006). It is argued that this left perisylvian network handles the processing of regularly inflected words (e.g. past tense or plural in English) that can be decomposed into stems and affixes, and are not stored as full forms. However, even very extensive damage to the left hemisphere can leave patients with substantial language comprehension abilities still intact, ranging from the ability to recognise simple spoken words to good comprehension of semantically predictable full sentences (Hagoort, 1997; Longworth, Marslen-Wilson, Randall, & Tyler, 2005; Tyler, Ostrin, Cooke, & Moss, 1995; Tyler et al., 2002, 2011).

This evidence has led to the proposal that two distinct but interdependent processing networks are involved in normal language comprehension – a distributed bilateral system supporting general perceptual and cognitive processing, and a specialised left-lateralised system responsible for processing specifically linguistic features. Bozic, Tyler, Ives, Randall, and Marslen-Wilson (2010) tested this assumption by co-varying the linguistic and non-linguistic complexity of a set of spoken words in an fMRI experiment. Non-linguistic complexity, realised by stem competition between the full form word and onset-embedded stem (e.g. *claim*/*clay*), activated a bilateral fronto-temporal network, including left and right BA 45 and BA 47. Linguistic complexity, defined here as the presence of a potential regular inflectional morpheme (e.g., real past tense forms, such as *played*, and pseudo-regulars, such as *trade*), activated only left hemisphere inferior frontal areas, peaking in BA 45.

These claims and findings, however, are primarily based on a single language, English, where the contrast between morphologically complex and simple forms has cross-linguistically unusual properties that may have led the neurocognitive processing system to organise itself in ways that are not generally representative. English inflectional morphology is very reduced in scope (with only three regular inflectional affixes[1]), and the majority of surface word forms in the language are produced as bare stems (*dog*, *eat*, *elbow*, etc.). This leads to a strong distributional contrast between words that are overtly morpho-phonologically complex (*jumped*,

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[1] These are the past tense {-d}, the noun plural and verb 3rd person {-s}, and the progressive {-ing}.

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eats, etc.) and those that are not. Furthermore, the complex forms typically have just one very frequent affix (such as the past tense {d}) that applies across the board to all eligible stems. This contrasts with a language such as Polish, a member of the Slavic language family, both in the prevalence of morphological complexity and in the richness and diversity of its inflectional system.

Almost all content words in Polish are overtly morpho-phonologically complex, realised within a rich inflectional paradigm. Nouns, which can be divided into three genders, inflect by case and number to give up to 14 possible forms (e.g. *dom* 'house, Nom', *domu* 'house, Gen', *domowi* 'house, Dat', etc.), and similarly for adjectives, numerals and pronouns. The verbal inflectional paradigm includes three tenses, with six person/number categories, as well as gender distinctions for past-tense forms (e.g. *robię* '[I] do'; *robisz* '[you, Sg] do'; *robiłem* '[I] did, Masc'; *robiłam* '[I] did, Fem'; etc.), together with affixes that express mood, voice and aspect. Additionally, verb stems undergo very common regular and irregular alternations (e.g. złościć 'to be/make angry': *złoszcz- / złości-*; or *trząść* 'to shake': *trzęse- / trzęsie- / trzęs- / trzęś-*; etc.), and fall into at least 9 (Grzegorczykowa, Laskowski, & Wrobel, 1999) or 11 (Tokarski, 1973) major inflection classes, most divided into subclasses. Conjugation tables of Polish verbs provide 106 types of conjugational paradigms, many with subtypes (Saloni, 2007). These distributional and morphophonological properties of Polish provide an appropriate set of contrasts for exploring the cross-linguistic validity of the dual processing networks proposed for English. Using the same fMRI testing paradigms, do we see a similar bilaterally distributed system activated by general perceptual processing complexity, coupled with a left lateralised response to specifically linguistic manipulations of morphological complexity?

Polish has benefited from a number of earlier studies looking at morphological processing in adults and children (e.g. Dabrowska, 2004; Reid, Marslen-Wilson, Baayen, & Schreuder, 2003) and in aphasic populations (e.g. Jarema & Kadzielawa, 1987; Ulatowska, Sadowska, & Kadzielawa, 2001), but the most relevant research is that of Jelowicka and colleagues. In a series of studies with fluent and non-fluent Polish aphasics, using the elicitation task (Jelowicka, Bak, Seniow, Czlonkowska, & Marslen-Wilson, 2006; Jelowicka, Bak, Seniow, & Marslen-Wilson, 2007, 2008), Jelowicka showed that non-fluent aphasics – with anterior LH perisylvian damage assumed to involve inferior frontal areas – showed problems primarily with the grammatical properties of stems and inflectional affixes. In contrast, fluent aphasics – with more posterior LH temporal damage – had apparently intact grammatical function, but showed substantial problems in basic operations of stem access. This is broadly consistent with a dual system analysis where stem access is a bilateral temporal function, whereas grammatical processing is more left-lateralised and frontal. However, the studies involved did not contain contrasts directly testing the questions raised here, and they primarily use production tasks. To evaluate Polish in the context of a dual network account, it is necessary to employ contrasts that are directly comparable to those used by Bozic et al. (2010).

The aim of the current study, accordingly, is to investigate the comprehension of morphologically complex words in Polish, asking how far the framework of two interdependent subsystems could be applied to this linguistically much richer and more complex system. To do so, we need to construct, as far as the language permits, equivalent kinds of contrasts to those that allowed us to selectively tap into each subsystem in English. In the English study, specifically linguistic increases in complexity were realised by the presence or absence of a regular inflectional morpheme – for example, the past tense form *played* contrasted uninflected forms such as *learn* or *clean*. This verb-based contrast cannot be transferred exactly into Polish, since all Polish verb forms have an inflectional suffix (marking person, number, tense, etc.). However, masculine nouns in the nominative case have no overt suffix (e.g. *dom* 'house, Nom'), even though they are suffixed for other cases and in the plural (e.g. *domu* 'house, Gen', or *domy* 'houses, Nom'). This contrast between masculine nominative and case-inflected nouns seems morpho-phonologically parallel to the contrast in English and is what we used in the experiment.

For English, the effects of increased linguistic complexity, driven by the occurrence of an inflectional affix, are strongly left lateralised (Bozic et al., 2010). The contrast between words with and without an inflectional ending produced significant effects only in LIFG, and was restricted to pars opercularis (BA 45). The strong lateralisation of this effect is consistent with a broad range of other studies using neuro-imaging and neuropsychological techniques (Embick et al., 2000; Marcus, Vouloumanos, & Sag, 2003; Marslen-Wilson & Tyler, 2007; Musso et al., 2003; Tyler et al., 2011; Vigneau et al., 2006), although there remains some dispute as to the key LIFG location supporting morphosyntactic functions. Pars triangularis (BA 44) is also implicated in many studies of these functions (e.g., Friederici et al., 2003). In the current context, we expect clear left lateralisation for the linguistic complexity manipulation, but leave open the specific locations in LIFG.

To explore the effects of general perceptual complexity, Bozic et al. (2010) used words with onset-embedded stems, such as *claim*. The conflict between the embedded stem *clay* and the whole word *claim* generated strong bilateral fronto-temporal activity, relative to words like *cream*, which have no embedded stem. In Polish it is again the masculine nominative nouns that allow us to mirror this contrast. Because these forms do not have a suffix, we can construct onset-embedded stimuli which do not additionally contain overt morpho-phonological cues to inflectional complexity – this would potentially obscure the intended contrast with linguistically complex pairs like *dom*/*domu*. We therefore selected masculine nouns in the nominative case which had onset-embedded stems, where these stems were also masculine nouns in a nominative case (e.g. *kotlet* 'cutlet', where *kot* 'cat', is the embedded stem). To allow possible comparisons between nouns and verbs, and to check that the results are not specific to nouns, we created a similar condition with verbs. Similarly to the nouns, these had uninflected onset-embedded stems (masculine nouns in the nominative), as in stimuli like *kwitnie* '[it] blooms', from *kwitnąć* 'to bloom', with *kwit* 'receipt' as the embedded stem.

In both embedded stimulus sets, following the results reported by Bozic et al. (2010), we expect to see neural activity varying as a function of the degree of competition between the embedded stem and the whole word, where this is expressed as the ratio of the frequencies of the whole word and the embedded stem. For English, effects of stem competition are seen bilaterally in inferior frontal cortex and (at lower thresholds) in superior and middle temporal cortex. The inferior frontal effects were seen primarily in pars orbitalis (BA 47), extending upwards into pars opercularis (BA 45), where they overlapped, on the left, with the effects of linguistic complexity.

To isolate the lexical processing network from lower-level auditory processing, we compared words against musical rain (MR), an acoustic baseline that is closely matched to speech in terms of its temporal envelope and amount of energy, but does not produce the perception of speech (Bozic et al., 2010; Uppenkamp, Johnsrude, Norris, Marslen-Wilson, & Patterson, 2006). Finally, we required a task that engages lexical processing, but at the same time can be applied to baseline non-speech items. Therefore we used passive listening with an occasional one-back memory task. The random distribution of the task trials across the scanning session ensures sustained attention of the participants, and because it is used only on a small number of dummy trials, these can be later removed from the analysis.