Neuropsychologia 71 (2015) 191–200

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Three-dimensional grammar in the brain: Dissociating the neural correlates of natural sign language and manually coded spoken language

Katarzyna Jednoróg [a,*], Łukasz Bola [b,e], Piotr Mostowski [c], Marcin Szwed [b], Paweł M. Boguszewski [d], Artur Marchewka [e], Paweł Rutkowski [c,**]

[a] Laboratory of Psychophysiology, Department of Neurophysiology, Nencki Institute of Experimental Biology, Poland
[b] Institute of Psychology, Jagiellonian University, Kraków, Poland
[c] Section for Sign Linguistics, Faculty of Polish Studies, University of Warsaw, Poland
[d] Laboratory of Limbic System, Department of Neurophysiology, Nencki Institute of Experimental Biology, Poland
[e] Laboratory of Brain Imaging, Neurobiology Center, Nencki Institute of Experimental Biology, Poland

ARTICLE INFO

Article history:
Received 12 November 2014
Received in revised form
30 March 2015
Accepted 31 March 2015
Available online 6 April 2015

Keywords:
Deaf
fMRI
Language comprehension
Sign language
Signed oral language

ABSTRACT

In several countries natural sign languages were considered inadequate for education. Instead, new sign-supported systems were created, based on the belief that spoken/written language is grammatically superior. One such system called SJM (system językowo-migowy) preserves the grammatical and lexical structure of spoken Polish and since 1960s has been extensively employed in schools and on TV. Nevertheless, the Deaf community avoids using SJM for everyday communication, its preferred language being PJM (polski język migowy), a natural sign language, structurally and grammatically independent of spoken Polish and featuring classifier constructions (CCs). Here, for the first time, we compare, with fMRI method, the neural bases of natural vs. devised communication systems. Deaf signers were presented with three types of signed sentences (SJM and PJM with/without CCs). Consistent with previous findings, PJM with CCs compared to either SJM or PJM without CCs recruited the parietal lobes. The reverse comparison revealed activation in the anterior temporal lobes, suggesting increased semantic combinatory processes in lexical sign comprehension. Finally, PJM compared with SJM engaged left posterior superior temporal gyrus and anterior temporal lobe, areas crucial for sentence-level speech comprehension. We suggest that activity in these two areas reflects greater processing efficiency for naturally evolved sign language.

1. Introduction

Research on sign languages of the deaf has greatly enriched our understanding of the neural representation of human language. For example, it has provided important evidence for modifying the classical view of the neural linguistic specialization, where the left hemisphere is specialized for language processing whereas the right for visuo-spatial abilities. Given the fact that sign language uses space, movement and visual imagery in ways not available to spoken language, the discovery of uniformity in the neural systems that mediate both sign and spoken language processing was an important, and largely unexpected finding (for review see MacSweeney et al., 2008).

At first, it might appear that differences between the two language types are likely to be driven by their respective modalities. Lesion and neuroimaging studies (Atkinson et al., 2005; Hickok et al., 1998; Marshall et al., 2004) indicate that it is predominantly the left-lateralized perisylvian network that supports both visual and auditory linguistic communication. Differences between the two language types are relatively minor: while sign language elicits more activation in the movement processing regions of the middle temporal gyri, spoken language activates to a greater extent the auditory processing regions of the superior temporal gyri (MacSweeney et al., 2002; Söderfeldt et al., 1997).

However, additional differences between the two language types arise from the fact that grammars of individual sign languages include structures and categories unattested in oral communication. For instance, sign languages can encode spatial

Abbreviations: PJM, (polski język migowy), a natural Polish Sign Language; SJM, (system językowo-migowy), devised system, Signed Polish; CC, classifier construction

* Corresponding author. Fax: +48 22 5892 490.
** Corresponding author. Fax: +48 22 552 08 69.
E-mail addresses: k.jednorog@nencki.gov.pl (K. Jednoróg), p.rutkowski@uw.edu.pl (P. Rutkowski).

http://dx.doi.org/10.1016/j.neuropsychologia.2015.03.031
0028-3932/

information linguistically via complex predicates usually referred to as classifier constructions, CCs (Emmorey, 2003). A CC is typically based on a particular handshape referred to as a "classifier" because its choice is driven by the most general physical properties of certain classes of entities, especially their shape and size. In contrast to regular lexical signs (e.g. nouns like MAN, WOMAN or CAR), classifiers do not denote specific entities but rather refer to broad and underspecified categories, such as vehicles, flat objects, thin objects, pipe-like objects, graspable objects etc. A CC is a combination of a classifier handshape and a three-dimensional component, such as motion or relative location (typically, a certain type of hand movement imitating the real-world movement of the entity referred to). For instance, if a signer produces two classifiers representing human beings and then moves his/her hands apart horizontally, the intended meaning is likely to be as follows: 'two people walked away in opposite directions'. Importantly, the exact form of a CC is determined by the spatial and dynamic properties of the three-dimensional aspect that is being mimicked (e.g. the motion of a vehicle will be represented differently from the way an instrument, such as a screwdriver, is handled by a human being). Unlike regular lexical verbs (like GO or DRIVE), CCs are subject to a wide range of modifications, reflecting the dynamics of the actions referred to (e.g. driving slowly vs. driving rapidly). Since CCs mime real-world activities visually, the phenomenon in question is very productive in sign languages, and has no direct equivalent in spoken communication.

Previous lesion studies suggest a specific role of the right hemisphere in both comprehension and production of CCs. Right hemisphere damaged signers performed well on tests of noun, verb and sentence comprehension, whereas they were impaired on locative sentences and CC comprehension (Atkinson et al., 2005). Along the same lines, Hickok et al. (2009) found that such patients made significantly more errors producing CCs than lexical errors in a narrative production task. Further evidence for the special role of classifier constructions in sign language comes from neuroimaging studies, which suggested the role of parietal cortices as markers of this spatial mode of communication. MacSweeney et al. (2002) showed that viewing topographic sentences which included CCs, compared to non-topographic sentences (without CCs) elicited greater activation in posterior middle temporal cortices bilaterally and left inferior and superior parietal lobules. These findings were extended by McCullough et al. (2012), who showed that sentences with motion CCs engaged motion sensitive posterior middle temporal cortices bilaterally (MT+), whereas left inferior and superior parietal lobules were specifically engaged by sentences with locative CCs. On the other hand, production of CCs compared to lexical signs has been shown to activate parietal lobes bilaterally (Emmorey et al., 2002) and this activity seems to be particularly robust for location and motion CCs, whereas the activity for object CCs was more similar to that elicited by lexical signs (Emmorey et al., 2013). The latter engaged anterior temporal lobes to a greater extent than CCs, which was interpreted as resulting from increased semantic processing required in the context of naming individual objects.

Beyond CCs, sign language offers a unique opportunity to study whether devised versus natural communication systems are processed differently in the human brain. In many countries around the world, natural sign languages of the deaf were (or still are) considered inadequate for education and interpretation purposes. This linguistic discrimination has its roots in the belief that spoken/written language is grammatically superior to visual-spatial communication. In the 20th century, many artificial sign-supported systems were therefore created, with the underlying idea that linguistic communication of the deaf should be based on the grammar of the spoken language used in a particular country. The situation in Poland is a vivid example of this historical development: independent of the naturally evolved Polish Sign Language (*polski język migowy*, PJM), the artificial Signed Polish (*system językowo-migowy*, SJM) was created in the 1960s and has since then been in use in schools and on public Television. SJM is a manually coded variety of spoken Polish. SJM borrows most of its vocabulary from PJM, i.e. the two communication systems use the same content signs (nouns, verbs, etc.). Additionally, the lexicon of SJM includes invented signs for functional (grammatical) elements that exist in Polish, but not in PJM. SJM preserves the grammatical and lexical structure of spoken Polish (with respect to, among others, word order, syntactic constructions, lexical collocations). For instance, the SJM verb 'lie' ('to be at rest in a horizontal position') – similarly to its Polish equivalent '*leżeć*'-'to lie' – combines with both human and non-human referents. In contrast, the same-looking sign cannot be used in the case of inanimate objects in PJM as it iconically represents two legs (with the pointing and middle fingers extended); the use of this sign in the context of objects leads to a semantic (visual) anomaly, which is ignored in SJM. Contrary to SJM, PJM is a full-fledged natural language, structurally and grammatically independent of Polish. The Deaf community has been very reluctant in adopting SJM, not least because it's much less efficient (slower) than PJM. SJM, as opposed to PJM, contains several features that are cumbersome in the context of a sign language, such as the use of prepositions, which are normally redundant in the three-dimensional signing space (spatial relations such as "under" or "above" are manifested visually, i.e. there is no need for prepositions). The underlying idea of sign-supported communication, namely the one-to-one correspondence between spoken/written Polish and SJM, makes SJM sentences longer to articulate and more difficult to comprehend than their PJM equivalents. Similar phenomenon could be observed in other sign languages, where artificially created signing systems, usually by non deaf people for educational purposes, are less effective in information transfer rate when compared to naturally evolved sign languages (Wilbur, 2009). Unnaturalness of SJM for native, fluent PJM users could originate not only from lower efficacy but also from lower learnability specific to modality (for e.g. manually coded languages have strictly sequential inflectional morphology borrowed from spoken language). In consequence, deaf children exposed solely to manually coded language resort to creating their own linguist structures to meet the modality constraints on signed languages (Supalla, 1991).

Here, for the first time, we compared the neural bases of a manually coded spoken language (SJM) as compared to a natural sign language (PJM). Our prediction was that the difference between the natural (PJM) and the devised (SJM) modes of communication should be visible in the perisylvian regions of the left hemisphere, since the two languages differ in their efficiency of visuo-semantic integration supported by these areas. Second, we also exploited the fact that PJM offers two grammatical options: the same intended meaning may be conveyed either with or without the use of classifier constructions. This allowed us to tease apart responses to CCs by contrasting SJM and PJM sentences that are structured linearly, i.e. do not employ CCs (SJM and PJM without classifier constructions, Fig. 1), and PJM sentences that are structured three-dimensionally (PJM with classifier constructions, Fig. 1). PJM without CCs was, therefore, a very important condition in this study. It was included not only to see if CCs affect the neural processing of signed sentences, but also to check if it is possible to trace any neural correlates of those grammatical differences between PJM and SJM that go beyond the use of CCs. Based on the literature, we predicted that sentences with CCs will activate parietal cortices to a greater extent than sentences without CCs. The reversed comparison should show the engagement of the anterior temporal cortex. In order to test for possible visual differences between the sentence types, such as amount of motion, a