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The Neuroscience of Sign Language

Introduction

The sign languages can be considered as natural languages used within the deaf communities all over the world. The Deaf Community In Poland uses the Polish Sign Language (pol. Polski Język Migowy, PJM), in France – the French Sign Language (langue des signes française, LSF), in USA – the American Sign Language (ASL). The spoken and the sign languages are conveyed with the different modalities of production and reception: the spoken language relays on the auditory-vocal modality, whereas the sign language is based on the visual-spatial modality. In other words, in order to formulate the speech the tongue and the mouth are to be applied so the voice can be transmitted to the auditory system. In spoken language the articulators are small and cannot be visually controlled by the speaker. While the signers use their hands, the facial expression and all their body so as to emit the messages out into the singing space that is the area in the front of the signer. Conversely, the main articulators in the sign language (hands) are comparatively big and can be visually controlled by the addresser of the information. Such signs are visually perceived by the addressee of the massage. The space is of the essential importance in the sign language: the great number of linguistic functions depends on the use of space (e.g. lexical, morphological and syntactic use of space) (Kotowicz 2015).

The studies regarding the hemispheric specialization have revealed that the left hemisphere is generally involved in processing the spoken language while the right hemisphere is responsible for processing the visual-spatial, non-linguistic relations. This cerebral predominance of the behavioral functions was attributed to the hearing individuals who are able to use the spoken language. It was a matter of the further concern for the scientists to investigate the hemispheric specialization of the deaf people who apply the sign language as the primary mode of communication. On one hand, the sign language is a natural language with the same quality and linguistic complexity as the spoken one, principally processed by the left hemisphere.

On the other hand, the sign language is a visual-spatial mode of communication and, when hearing people are taken into account, the visual-spatial non linguistic relations are processed by the right hemisphere. Therefore, the researchers were willing to clarify whether the deaf signing subjects would have a distinct cerebral dominance with regard to the visual-spatial linguistic and non-linguistic tasks (Campbell, MacSweeney, Waters 2008; Rönnberg, Söderfeldt, Risberg 2000).

The Spoken Language and the Brain Damage

When taking the spoken language into account, the investigation regarding the patients with the brain injury (lesions) might be the first source of information that helps to uncover the connection of the certain brain areas and their linguistic functions. In the 19th century Paul Broca described the patient who suffered from the left hemisphere, frontal lobe brain damage (Broca's area). Those lesions were causing the specific speaking difficulties: the patient was only able to pronounce the automatic, well learned phrases (such as invectives, prayers) but could not produce a comprehensible sentence by himself. This patient had essential problems when attempting to build the grammatical structure of the sentence, while he was capable of understanding the spoken language. This kind of language disorder, caused by the brain injuries, is called now the Broca's aphasia. The left frontal areas seems to be essential for speech production but not for understanding (Campbell i in. 2008; Rönnberg i in. 2000).

The brain regions involved in the speech comprehension were discovered by Carl Wernicke. The famous German neurologist has analysed the patients with the upper left temporal cortex damage (the Wernicke's area) whose speech production was not disturbed (although they suffered from the minor difficulties such as inability to name the particular objects) and who were lacking the capability of language comprehension. Those patients were able to utter words and employ the grammar but still it was highly problematic for them to produce the meaningful sentence. Their speech was senseless as they were not able to understand their own words. Nowadays, this kind of language dysfunction caused by the brain damage is labelled as the Wernicke's aphasia (Campbell i in. 2008; Rönnberg i in. 2000).

It is worth mentioning, that the classical Broca's production area (the lower lateral part of the frontal lobe) and the classical Wernicke'a receptive area (the upper part of the lateral temporal lobe) are located within the left hemisphere, near the Sylvian fissure and are described as the perisylvian regions. Those parts of the cortex appear to be crucial for the language processing when the hearing people who apply the spoken language are take into account (Campbell i in. 2008; Rönnberg i in. 2000). However, as per the deaf signers' brain, one could enquire whether those perisylvian areas play the comparable part in language production. Could the sign language considered as the visual-spatial language resist the right-sided brain injuries while being affected by the left-sided damage? Is there any dissociation between sign language processing and the non linguistic visual, spatial and motor abilities?

The Brain Injuries of the Signers.

The pioneering book of Poizner, Klima and Bellugi (1987) entitled: "What hands reveal about the brain?" can be considered as the first attempt to determinate the cortical substrate of the sign language. The scientists have analysed six distinct cases of the deaf patients suffering from the one side brain injuries for whom the American Sign Language (ASL) was the dominant mode of communication. Three of them had left-hemisphere lesions. These subjects had no difficulties in completing the non-linguistic visual-spatial tasks. However they had poor sign recognition and problems in sentence comprehension. They were diagnosed as suffering from the sign language aphasia that had similar manifestations as the spoken language aphasia (Poizner i in. 1987).

According to the scientific studies (Bellugi, Poizner, Klima 1983; in: Rönnberg i in. 2000; Poizner i in. 1987, 1990) the left frontal cortex damage (Broca's area) seems to affect the ASL production with good signing comprehension and it is labelled as the Broca's-like sign aphasia. First and foremost, those patients have problems when employing the sign language grammar. The left posterior-temporal cortex injuries (Wernicke's area), called, results in the comprehension disorders while the fluent production of the sign language is preserved are called the Wernicke's-like sign aphasia. Those patients are able to produce the jargon signing which is difficult to understand (Bellugi i in. 1983; in: Rönnberg i in. 2000; Poizner i in. 1987, 1990).

The research on left-lesioned patients have revealed that the problems regarding the linguistic motor are dissociated from disorders involving the general, non linguistic activity, including gestures or facial recognition (Marshall, Atkinson, Thacker, Woll, Smulevitch 2004). As per the Kimuras apraxia test (Kimura's Movement Copying Test), checking the capability to imitate the unfamiliar and meaningless movements, the performance of the patients suffering from the left-sided damage was average. However, it was difficult for them to imitate the parameters of the sign language (Hickok, Kritchevsky, Bellugi, Klima 1996; in: Rönnberg i in. 2000). Subjects with left hemisphere injuries achieved good scores when tested in pantomime recognition but whereas their sign language comprehension was disturbed. Left-lesioned patients obtained normal results on Benton Facial Recognition Test but they could have problems with processing facial expression when used as a part of the sign language grammar (Poziner i in. 1987).

The other three patients involved in the research made by Poizner i in., (1987) had right-sided brain lesions and did not demonstrate any problems with regard to the ASL production nor comprehension, although they had difficulties in non-linguistics visual-spatial processing. The patients suffering from the hemisphere brain damage use the space correctly, including the left side while signing.These patients usually neglect this area while drawing (they ignore the left side of the picture) but their sign language communication (both production and comprehension) remains intact, as it was demonstrated in the research of Corina, Kritchevsky and Bellugi (1996): the deaf patient with left-visual field neglect had visuospatial non-linguistic objects processing impaired, whereas the sign identification was not impaired.

Poizner i in. (1987) described a very prominent example of dissociation between spatial language processing and non-linguistic cognition. The patient who, prior to the damage, was an artist with excellent painting skills suffered from the right-hemisphere lesion. After the injury the women has lost her artistic, non-linguistic abilities whereas the sign language visuospatial processing skills were not disturbed. This case was an evidence that the visuospatial and motor linguistic functions are separate from non-linguistic visuospatial and motor functions.

Reported inquiries on the spoken and the sign language aphasia have revealed the unexpected compatibility with brain damage studies. The gathered data regarding the lesion cases data have proved that the left hemisphere is specialized and involved not only in spoken language, but also in the sign language processing. As the sign or spoken language users have injuries in perisylvian regions, they suffer from the language disorder. The classical left-hemisphere structures involved in the spoken language comprehension and production are also important for the sign language. All these considerations can be treated as an evidence that the sign language has the status of the natural language with equivalent neuronal basis as spoken language.

However, we should consider the data based on brain injuries with caution. Firstly, in these research, the scientists analyse the aberrant brain activity as a direct result of the incurring damage. Lesions might inhibit certain processes as well as enhance other actions. The compensatory mechanisms and the brain flexibility after the injuries could change the operational activity of certain cortex regions. Secondly, the studied cases regarding the deaf patients using sign language as the first mode of communication with one sided brain damage are rare and usually the injuries pertain to various areas beyond the classical perisylvian regions. For these reasons, the new methods of brain functioning analysis could much more efficiently illuminate the cortical substrate of the sign language. Nowadays we have the capacity to analyse the brain activation of the healthy subjects without lesions. Researchers can use *inter alia*: EEG (electroencephalography), PET (positron emission tomography), ERP (event-related potential) or fMRI (functional magnetic resonance imaging).

The Brain Activation and the Sign Language.

As per the subjects without brain injuries, the sign and spoken languages processing entail the activation of the dominantly left-lateralized perisylvian network. Additionally, the imaging data have shown also the right hemisphere involvement during sign language processing (e. g. Hickok, Bellugi, Klima 1998; Jednoróg i in. 2015; Neville i in. 1998).

In some inquiries regarding the sign language processing the scientists have observed the unique brain activation not common to the spoken language. For example the deaf native signers ERP study has evidenced the posterior temporal and occipital regions activation not observed in the hearing native signers group. Neville, Coffey, Lawson, Fischer, Emmorey and Bellugi (1997) have suggested that the deafness can increase the activity of the visual cortical regions. Language processing activated right hemisphere and parietal cortex of deaf and hearing native signers (Neville i in. 1997).

Söderfeldt, Rönnberg and Risberg (1994) and Söderfeldt, Ingvar, Rönnberg, Eriksson, Serrander and Stone-Elander (1997) have compared the brain activity associated with two languages processing: the Swedish Sign Language and the spoken Swedish. The first PET data revealed no differences between activation during the sign or the spoken language processing. The second study including more detailed analysis has evidenced that the applied spoken language involved the different brain activation when coupled with the sign language. The Sign Language activated posterior and inferior temporal and occipital regions (visual cortex) whereas the spoken language was connected with activation of the superior temporal lobe (auditory cortex). These differences are connected with modalities used by each of the languages. However, both languages (the spoken language and the sign language) resulted in the comparable perisylvian regions activation.

Age of Acquisition

Age of language acquisition has implication for neural system supporting not only spoken language but also the sign language processing. In deaf community the majority of individuals have delayed and/ or impoverished exposure to sign language. The great number of deaf start to sign in their late childhood, adolescence or even in the adulthood. Most often the hearing parents of the deaf children do not use the sign language at home and the education applied does not sufficiently involve the sign language. The late deaf sign language learners have lower competence in sign language (Lieberman, Borovsky, Hatrak, Mayberry 2015) and different brain activation than other deaf native signers (e.g. MacSweeney, Waters, Brammer, Woll, Goswami 2008; Mayberry, Chen, Witcher, Klein 2011).

Mayberry i in., (2011) used fMRI method to analyse the brain activation of the deaf adults with different age of ASL acquisition (varying from birth to the age of fourteen). Participants were scanned while performing linguistics tasks in American Sign Language (these involved the grammatical judgment and the phonemic-hand judgment tasks). The age of acquisition of the sign language was negatively correlated with the anterior language areas activation: when the sign language acquisition was initiated at the young age, the classical language regions were mobilized during both linguistics tasks. Activations of the typical language areas decreased in case of the sign language late learners, even if these persons were using the sign language for over twenty years as a primary mode of communication. Age of the sign language acquisition was positively correlated with posterior visual regions (occipital cortex). The signers with the late language acquisition concentrated on the visual properties of signs (Mayberry i in. 2011) while the early learners of sign language showed decreased activation in occipital cortex. To sum up, late sign language learners even those who use it approximately for two decades have different organization of the neural sign language processing than adults initiating the sign language acquisition at the early age.

The MacSweeney i in. (2008) fMRI study has evidenced that the deaf late sign language learners have greater activation of the left inferior frontal gyrus than the deaf native signers performing British Sign Language (BSL) task (phonological similarity task). In addition, the same difference was discovered when the participants were solving phonological similarity task in written English. Both groups (the early and the late sign language learners) acquired written English at the same age (during their school years). The left inferior frontal gyrus was better activated in case of the late bilinguals (the late learners of the second language) in contrast to early bilinguals (the early second language learners) (Wartenburger i in. 2003; in: MacSweeney i in. 2008) and in low versus high-proficiency late language learners (Chee i in. 2001; Wartenburger i in. 2003, in: MacSweeney i in. 2008). MacSweeney i in. (2008) research has shown that the age of the first language acquisition is important for the brain activation not with regard to the first language processing but also when the second language is employed.

Even for the late sign language learners the sign language experience can have impact on the cortical activation when performing the sign language tasks (Ramirez, Leonard, Torres, Hatrak, Halgren, Mayberry 2014). Ramirez i in. (2014) have presented the longitudinal study that considered the brain activation of two deaf adolescent (the late sign language learners) who had their first access to the sign language at the age of fourteen. Those two subjects with two/ three years of sign language experience had atypical cortical activation during lexico-semantic processing (the activations were generally located to right dorsal frontoparietal areas). After the sign language was employed for additional fifteen months the organization of the neural sign language processing has changed with regard to certain tasks. The atypical neural activation was still present when processing less familiar signs, however, when participants analysed highly familiar signs, they activated more left-hemisphere perisylvian language areas. Under certain conditions –when processing the highly familiar signs the brain activation of the late sign language learners processing the sign language can evolve from atypical localization to more classical language regions (Ramirez, Leonard, Torres, Hatrak, Halgren, Mayberry 2014).

The sign language processing involves different brain activation also for the hearing individuals when the age of the sign language acquisition is to be taken into account. Newman, Bavelier, Corina, Jezzard and Neville (2002) compared the organization of the neural network while performing the sign language task in the group of native hearing signers (ASL and English early bilinguals) and hearing late learners of the sign language. Only the native hearing signers activated the right hemisphere angular gyrus while processing the sign language whereas the late learners highly proficient in sign language didn't have neural activation in the right hemisphere.

Conclusion

The lesion and neuroimaging data confirm that processing the sign and the spoken language involve activation of the similar cortex areas: the perisylvian regions in the left hemisphere. Regardless of their modality (auditory-vocal in spoken language and visual-spatial in sign language), the natural languages have similar cortical substrates. At the same time, they are some differences of the neuronal systems that mediate the spoken and the sign language: auditory-vocal language entail auditory cortex, whereas the visual-spatial language activates visual cortex. The role of right hemisphere can be more significant for the sign language processing than for the spoken language however not all the scientists agree with this idea (Campbell i in. 2008). The age of the sign language acquisition has impact on the sign language system equally for the brain of the deaf and the hearing signers. In case of deaf subjects the sign language acquisition can be also important for the second language processing.

To sum up, the neuroscience research regarding the sign language enlarge the scope of knowledge that pertain to the visual-spatial languages, and they are not only essential for the ASL but for the Polish Sign Language that nowadays is being investigated by the neurobiologists. These findings can help us to understand, the impact of the modality on the cortical network responsible for language processing and, on the other hand, universals of neuronal organization of natural language independently of language modality.

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Abstract

Current brain damage and neuroimaging research have shed some light on the neuronal network of the sign language processing. Similar manifestations of the left-sided sign language hemispheric specialization was observed in the case of sign language aphasia as in the spoken language aphasia. Lesions clinical data reveals the dissociation between the spatial language abilities and the non-linguistic visuospatial and motor functions. Signers with no brain damage activate left-sided perisylvian area, the classical spoken language regions which seem to be important for the language processing independently of the language modality. Neuroimaging data have allowed to differentiate the cortical system mediating the sign language (the activation of the visual cortex) that is distinct from the spoken language area (the activation of the auditory cortex). Additionally, the age of acquisition seems to have impact on the brain activation during the sign language production and reception in the case of both deaf and hearing signers as well.

Keywords: language processing, neuroscience, sign language

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asystent Instytutu Pedagogiki Specjalnej na Uniwersytecie Pedagogicznym im. Komisji Edukacji Narodowej w Krakowie, doktorantka Uniwersytetu Jagiellońskiego, studentka psychologii na Uniwersytecie SWPS, członek Laboratorium Psychologii Języka i Dwujęzyczności w Instytucie Psychologii Uniwersytetu Jagiellońskiego. Zainteresowania badawcze: dwujęzyczność migowo-foniczna, edukacja dwujęzyczna, język migowy, procesy poznawcze głuchych i słyszących osób posługujących się językiem migowym.