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The influence of the age of acquisition of a foreign language on the activation patterns of language areas

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Summary

Background: The of aim of the present study was to evaluate the influence of the acquisition age of the second language on activation patterns of language areas.

Material/Methods: Forty volunteers participated in the study (20 females and 20 males). Their age ranged from 18 to 40 years. A mean age was 28 years. All participants had possessed a high proficiency of the acquired foreign language. They were divided into two groups, according to the age of the foreign language acquisition. The participants who acquired the second language before puberty, were qualified to the early acquisition group. The remaining participants were qualified to the late acquisition group. The second criterion was the level of the acquired, foreign language. Proficiency in using the language was assessed by a teacher.

Block design method was used in the performed experiment. The experimental task was speech production in the form of voiceless sentences, the control task was silence. Each experimental session consisted of five 30-second alternating blocks. Every volunteer participated in two sessions, where she/he described his house without the use of voice. One session applied the native language, L1, and the other one the foreign language, L2. The experiment was performed using MR Signa Horizon system (GE Medical Systems, USA) with 1.5 T magnetic field strength. Functional images were obtained using the echoplanar sequence (EPI) that applies spin echo and is sensitive to the changes of the BOLD (Blood Oxygenation Level Dependent signal) signal having the following parameters: TR =3000 ms, TE =60 ms, flip angle 90°, FOV =28×21 cm, matrix 96×96 pixels, 1 NEX. Functional data analysis was performed using SPM2 software (Wellcome Department of Cognitive Neurology, Great Britain).

Results: In EA and LA groups, the cortex activation was not more intense in patients speaking their native language, as compared to the foreign language. In the LA group, left inferior frontal gyrus (*pars triangularis*) showed more activation in L2. In the EA group, the activation in L2 was found in inferior frontal gyrus (*pars triangularis*) and in a small part of the left middle frontal gyrus.

Conclusions: The Age of acquisition of the foreign language influences the pattern of activation of language areas, mainly in regions involved in syntax. Early age of acquisition allows one to acquire the rules of syntax in L2 in a similar manner as in L1.

Key words: fMRI • bilingualism • age of acquisition

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Background

There are variable views on brain models of language function. The results of examinations carried out with the use of PET and FMRI confirmed the role of the classical language areas but, at the same time, provided the researchers with new information on language organisation within the brain [1]. First of all, it turned out that the classical language areas are not functionally homogenous – they consist of smaller areas responsible for the specific aspects of language [2]. Secondly, the language-connected brain activity was not limited to the classical areas. Thirdly, it was

proved that the functional division of the language structures of the brain is rather subordinated to the linguistic aspects (semantics, syntax etc.) than the specific activities connected with language – such as speaking, reading, listening [3]. There is also a whole range of views on the brain bases of bilingualism. Grosjean [4] estimated that approx. 50% of the world population uses more than just one language. According to that researcher, bilingualism is a world-wide standard. The issue whether the areas responsible for language functions in the first and second language overlap or are totally separate has long been the subject of disputes. The literature describes clinical cases of aphasia in which the ability to speak native language got disturbed although the patient was still able to speak the second language, which suggested that speaking different languages involved different brain areas [5,6]. However, other experiments did not produce such unambiguous results [7–10]. The studies trying to evaluate the influence of the acquisition age on speech centre location in the brain turned out to be extremely interesting as well [11,12]. Paradis [13] suggested a theory in which the method of L2 acquisition determined the degree of procedural or declarative memory involvement. If both L1 and L2 was acquired in the course of a direct contact with the environment before the age of 7 and the speaker is fluent in L2, then the aspects of syntax and morphology are stored in the system of the procedural memory. Language acquired at school, connected with a lower level of fluency, tends to involve the system of the declarative memory. These two kinds of memory are connected with different brain mechanisms of different anatomical location in the left hemisphere. Paradis underscored the meaning of the medial structures of the temporal lobe in the declarative memory and of the basal ganglia in the procedural memory. Ullman [14] developed and expanded this view. According to the declarative/procedural memory model, the acquisition of grammar of the native language involves the procedural memory, while memorising the meaning of the native words requires the activation of the declarative memory. In the acquired language, the involvement of these two memories is different, as compared to the native language. Acquiring grammatical rules of L2 depends on the procedural memory in early childhood, and on the declarative memory at a later age. The later the L2 learning process takes place, the higher the involvement of the declarative memory in grammar acquisition. The views of Paradis and Ullman were questioned by Perani, who provided evidence for the fact that the organisation of language functions in the brain is the same for both languages [15]. According to this author, the differences in the neural representation of those functions depend on such factors as the acquisition age, the level of fluency and the degree of contacts with the language. These factors influence the area involved in foreign language processing within the same (as in the native language) neural system. Although the language can be learnt at any age, it is rare that its level of knowledge is comparable to the level of the native language if the learning process started after the 'critical period', i.e. after puberty [16,17]. It was proved that there are no differences in grammatical processing of the native and the acquired language in individuals who know the language from childhood and are fluent in it, as opposed to those who learnt to use the language after the age of 6 and are proficient in it: they engage larger areas of the brain (when solving grammar tasks in the foreign language) but only within the structures connected with language (e.g. Broca's area). This speaks for the fact that both languages are organised within the same neural system [18]. The age of language acquisition does not influence the lexical aspect. So far, there has not been many studies on the production of speech (in the form of a free utterance) by bilingual individuals [19]. These were mostly the particular aspects of speech, separately connected with syntax or phonology, as well as semantic aspects, that were studied. Many authors pose the following question: does the acquisition age influence the patterns of language area activation? According to some authors, the influence of the acquisition age is closely connected with the degree of foreign language level [16,17]. They claim that the influence of the acquisition age is the most apparent in the aspect of syntax processing, while the lexical-semantic aspects depend mostly on the level of language fluency [18]. Authors agree that similar linguistic areas of the brain take part in speech processing and grammar acquisition in L1 and L2, irrespective of the acquisition age; however, there are differences in the degree and range of their involvement [15,18]. It is assumed that when comparing two groups of people with a good knowledge of the foreign language and a different age of language acquisition, it is possible to find some differences in the patterns of activation of the structures connected with phonological and syntactical processing during foreign language speaking. This should allow for an evaluation of the influence of the foreign language acquisition age on the patterns of cortical language area activation.

Material and Methods

The experiment involved 40 individuals (20 women and 20 men) in the age ranging from 18 to 40 yrs. The mean age was 28 yrs. The participants, who acquired a good knowledge of a foreign language, got divided into groups, according to the age of foreign language acquisition. Individuals who acquired a foreign language before puberty were qualified to the 'early acquisition' group (EA). Others were qualified to the 'late acquisition' group (LA). The level of the foreign language was assessed by a teacher, on the basis of a four-point scale evaluating the fluency and the correctness of pronunciation. Both groups achieved results confirming their fluency in the foreign language.

The 'early' age of language acquisition meant that a given person learnt the foreign language before puberty. In the material used for the purposes of this work, these were the individuals who were acquiring the second language from the moment of birth – children of mixed marriages (bilingual). Persons qualified to the LA group started to learn the second language after the age of 16. The mean age of acquisition in this group amounted to 19.7 yrs. The native language of the participants was Polish and Norwegian, while the foreign language was English.

Block design method was used in the performed experiment. The experimental task involved speech production in the form of voiceless sentences. The control task was silence. The experimental task consisted in describing one's place of residence in the form of a silent utterance, which involved

different aspects of language. This task based on generating words, which is connected with speech production, i.e. its phonological aspect. The control task involved silence, which enabled the researchers to observe language areas active during movements of the speech organ and areas active during phonological processing. This task allowed for an observation of brain activity connected with semantics, because it required lexical selection of specific words and their reproduction on the basis of the semantic memory. Because the description of the flat was done with the use of full sentences, the task required application of correct syntax, which involved a good knowledge of grammar.

Each experimental session consisted of five 30-second alternating blocks. Every volunteer participated in two sessions, where she/he described his house without the use of voice. One session applied the native language, L1, and the other one the foreign language, L2. The experiment was performed using MR Signa Horizon system (GE Medical Systems, USA) with 1.5 T magnetic field strength. Functional images were obtained using the echoplanar sequence (EPI) that applies spin echo and is sensitive to the changes of BOLD (Blood Oxygenation Level Dependent signal) signal having the following parameters: TR =3000 ms, TE =60 ms, flip angle 90°, FOV = 28×21 cm, matrix 96×96 pixels, 1 NEX. Every experimental session involved obtaining 50 volumes of the brain, with every volume consisting of 10 slices of the head, 7 mm each. The slices were axially oriented, parallel to the line connecting the anterior and posterior commissure of the brain. In every patient subjected to the study, the lowest slice was placed 14 mm below the aforementioned line.

Functional data analysis was performed using SPM2 software (Wellcome Department of Cognitive Neurology, Great Britain) installed in Matlab (Mathworks, USA).

Results

To evaluate the influence of the acquisition age on the activation patterns of the language areas on the basis of a contrast analysis, we examined the differences in brain activation in the first and second language, in two groups of studied individuals: LA and EA. By analysing the contrasts, we performed the comparison of brain activity in the process of foreign (L2) and native (L1) language speaking, in both groups. The contrast had the form of L2>L1, i.e. voxels for which the statistical t value exceeded the threshold of statistical significance signified those areas in which the brain activation during foreign language speaking was significantly higher than during native language speaking. We separated voxel clusters for which brain activation strength in L2 was higher than in L1. We counted the number of voxels in every cluster of activation. Maximal activity values were marked as 'Z values', and their stereotactic coordinates as 'x', 'y', and 'z'. The opposite comparisons, i.e. L1>L2 were performed with the same method. In the LA group, the analysis of activation differences between L2 and L1 (contrast L2>L1) revealed activation within inferior frontal gyrus (pars triangularis, Broca's area). That was the area with a significantly stronger activation during foreign language speaking than during first language speaking. The results of the analysis were presented in Table 1, Figures 1, 2 and 3. The opposite analysis – i.e. L1>L2 – did not reveal any significant differences between individuals speaking L1 and L2. The analysis in the 'early acquisition' group was carried out in the same way as the one discussed in the previous group. The comparison of brain activity during L2 and L1 speaking (L2>L1) revealed activation in one cluster, located in the inferior frontal gyrus and in the part of the middle frontal gyrus (Broca's area). The results were presented in Table 2, Figure 4, 5, and 6. The comparison of the activity strength in the first and second language (L1>L2) did not reveal any significant differences. Those who acquired foreign language early, as well as those with late acquisition revealed statistically significant, stronger activation of the brain during foreign language speaking, located in the inferior frontal gyrus mainly. In the 'late acquisition' group, the activation representing a maximal difference between the L2 and L1 was located within the inferior frontal gyrus, corresponding to the Brodmann's area 44. In the 'early acquisition' group, an analogous comparison revealed a cluster of voxels located more dorsally, at the borderline of the inferior frontal and the middle frontal gyrus. In order to show the influence of the acquisition age on the language area activation patterns, we compared locations of those activated areas. Both clusters of voxels coded with appropriate colours were presented jointly in the coronal, sagittal, and axial images of the brain. The results were presented in Figure 7.

Discussion

In the 'late acquisition' group, the activation representing a maximal difference in the L2>L1 contrast was located in the inferior frontal gyrus, corresponding to Brodmann's area 44, while in the 'early acquisition' group an analogous comparison revealed a cluster of 47 voxels located more dorsally, at the borderline of inferior frontal and middle frontal gyrus, with its larger part being placed in the middle frontal gyrus, and only a small part in the inferior frontal gyrus. In individuals with late language acquisition, the cluster of voxels was located within the inferior frontal gyrus. This may lead to a conclusion that the age of foreign language acquisition influences the aspects of syntax and grammar. In individuals that acquired foreign language at an early age, the activation difference found between the L1 and L2 is insignificant and concerns only a small part of the pars triangularis, and a larger part of the middle frontal gyrus, responsible for taking semantic decisions or processing the content of the story. Pars triangularis was also active in the dorsal part, adjacent to the orbital part connected with semantics, i.e. with recalling words from the semantic memory. This means that those individuals who acquired the foreign language at an early age, showed insignificant differences between L1 and L2 in the areas connected with syntax (pars traingularis constituted only 31% of the cluster that was composed of 47 voxels) but slightly higher differences in the areas connected with semantics (62% of that cluster) than the individuals who acquired the language after puberty and revealed the differences between L1 and L2 only in the area connected with syntax (pars traingularis – 75 voxels). It may be then concluded that those individuals who acquire foreign language before puberty, acquire the abilities of syntax rule application at a level equal to the native language, which

Table 1. Comparison for contrast L2>L1 analysis in late acquisition group.

Location	Hemisphere	Number of voxels	Z value	x	y	z
Interior frontal gyrus (*pars triangularis*)	Left	75	3.35	–46	36	6

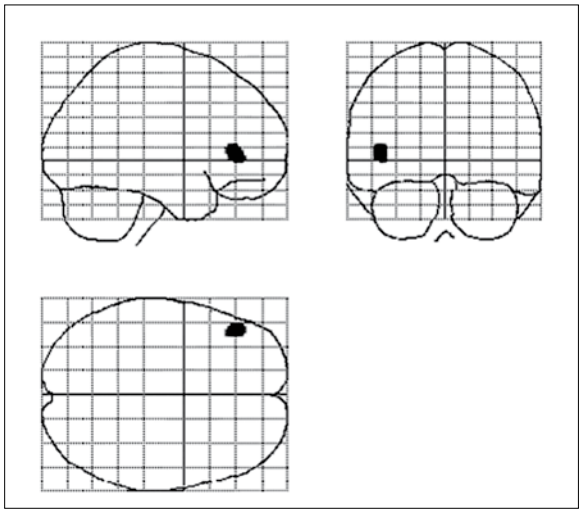

Figure 1. Activated area for L2>L1 contrast in late acquisition group shown on a sagittal, coronal and axial diagram.

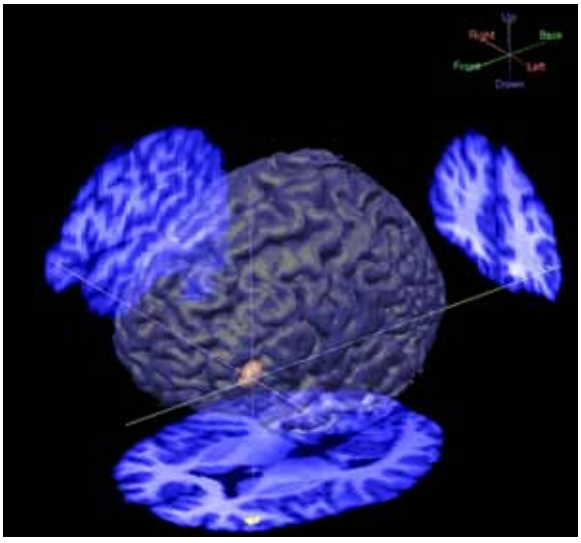

Figure 3. Activated area for analysis of L2>L1 contrast in late acquisition group shown in 3D image and in coronal, sagittal, and transverse cross-sections.

Figure 2. Activated area for the L2>L1 contrast in late acquisition group shown on axial images.

would confirm the reports on the influence of the acquisition age on the application of the foreign language [18]. As already mentioned in the introduction, the literature on bilingualism does not agree whether the acquisition age has a direct influence on the patterns of brain activation in bilingual individuals or whether the differences in activation patterns in individuals with early and those with late language acquisition have any connection with different levels of language fluency [19,20]. The influence of the acquisition age on speech production in bilingual persons, with respect to the syntactic and semantic aspects, was studied by Wartenburger in the aforementioned work from the year 2003 [18]. The study involved tasks that aimed at finding the semantic and syntactic mistakes. It showed that semantics depends mostly on the level of the speaker's semantic knowledge, while the age of language acquisition influences first of all the aspects connected with syntax. While performing the tasks connected with grammatical

Table 2. The table shows the results of contrast L2>L1 analysis in early acquisition group.

Location	Hemisphere	% cluster	Number of voxels	Z value	x	y	z
Middle frontal gyrus	Left	62	47	3.55	–42	42	18
Interior frontal gyrus (*pars triangularis*)	Left	31					

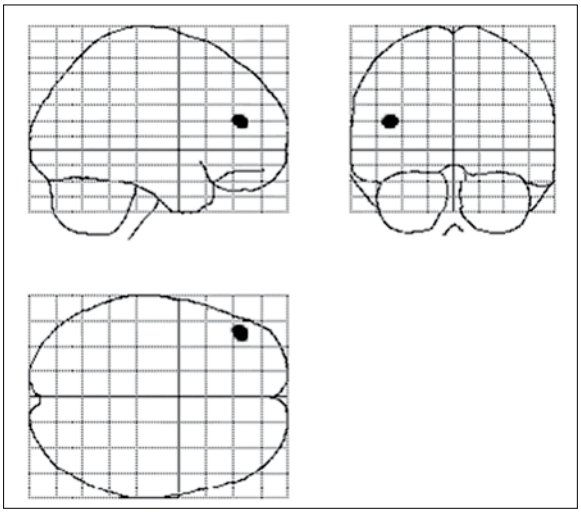

Figure 4. Activated area for the L2>L1 contrast in early acquisition group shown on a sagittal, coronal and axial diagram.

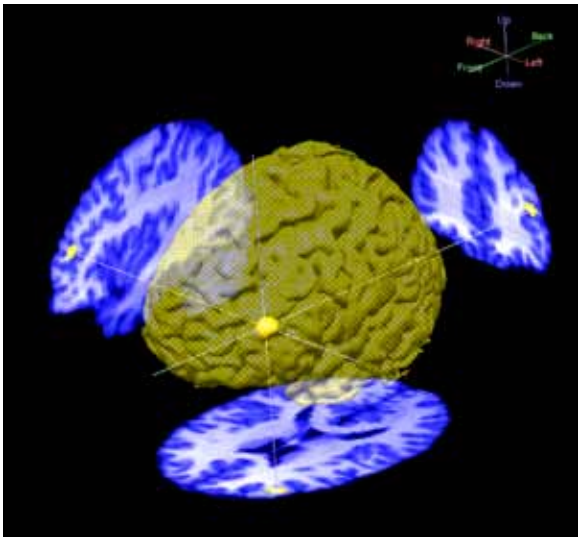

Figure 6. Activated area for analysis of L2>L1 contrast in early acquisition group shown 3D image and on axial, coronal and sagittal cross-sections.

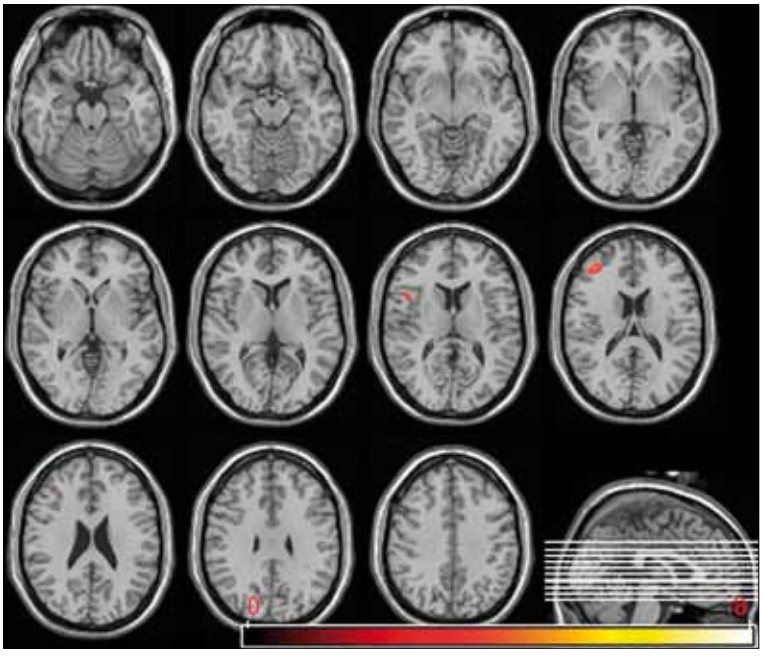

Figure 5. Activated area for the L2>L1 contrast in early acquisition group shown on axial images.

aspect evaluation, the study group that was proficient in the foreign language and acquired it at a late age, activated bilaterally the inferior frontal gyrus in a higher degree than the group that acquired the language early and new it well. This confirms the results obtained in our study, showing that those individuals who acquired foreign language at a later age, activate the inferior frontal gyrus in a higher degree than those who acquired such a language earlier. In 2003, Perani studied the influence of the foreign language acquisition age on the cortical representation of the foreign and native language [21]. The examination involved a group of eleven individuals who acquired the foreign language at a late age (after the age of 3) and knew it very well. The experimental task consisted in generating

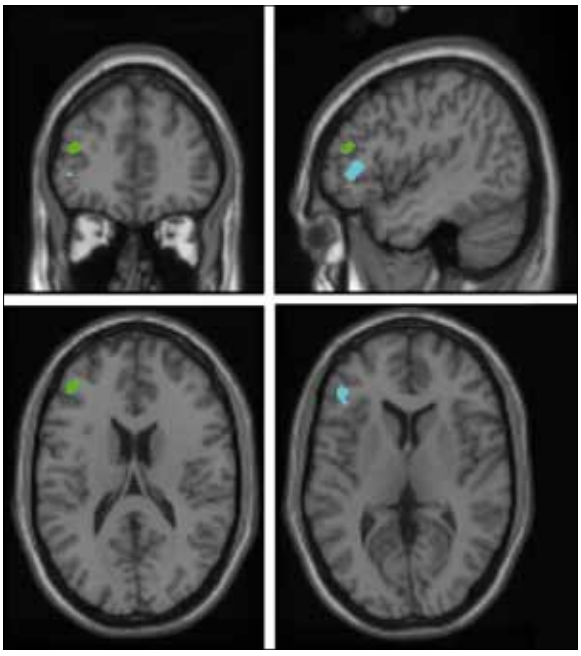

Figure 7. Comparison of activation (L2>L1) location in late acquisition group – blue colour – and (L2>L1) in early acquisition group – green colour.

words starting with a specific letter in language L1 and L2. The results obtained in that paper point to a considerable influence of the foreign language acquisition age, although all studied individuals learnt this language relatively early and were fluent in it. The comparison L1 – L2 did not reveal any significant activation, while the L2 – L1 revealed areas of higher activity in L2, which points to the fact that those individuals who acquired foreign language as early as at the age of three, show some differences in cortical structures activation in L1 and in L2. This is all in accordance with our study results (the study group in Perani's paper corresponds to the EA group in our study). Areas of higher activation in L2 included, both in the study by Perani and in our study, the inferior frontal and inferior middle gyrus of the left lobe. Another work on language production resulted in different outcomes. Chee et al. (1999) [22] revealed with the use of the functional magnetic resonance imaging that there are no differences within the left prefrontal cortex activation between the individuals who acquired the foreign language at an early age and those who acquired it later. They examined a group of 15 bilingual individuals who acquired the language at an early age and 9 bilingual individuals who acquired it at a late age. They all spoke English and Mandarin. The most activated area in their experiment was the prefrontal region. The task which consisted in the production of words did not result in any differences in brain activation in those two groups, although both languages differ substantially in their structure. The study by Urbanik et al. [23], concerning the influence of the foreign language level on the organisation of language functions within the brain applied the same research procedure as our work but led to different results. Those individuals who acquired the foreign language at an early age and knew it well did not reveal any differences in the strength and range of activation of the cortical areas between L1 and L2. The authors observed a higher activation of cortical areas in the foreign language, in individuals who were not proficient in that language. The differences between the study by Urbanik and our study could result from a different number of the study individuals (larger study group in our paper). In 1997, Kim et al. carried out an experiment on 6 volunteers who learnt foreign language in early childhood and six volunteers who acquired foreign language after puberty. Both groups were fluent in that language. The experimental task consisted in describing morning, afternoon, and evening activities in full sentences, in silence. The results of the experiment showed that the age of acquisition influences the activity of the inferior frontal gyrus (Broca's area). In individuals with earlier acquisition of the foreign language, the activity within the Broca's area observed during L1 speaking overlapped (was located in the same place) with the one observed during L2 speaking. In late acquisition, the location of the regions within the Broca's area observed during L1 and L2 speaking was not the same. Kim concluded that the age of language acquisition influences speech organisation in the brain of bilingual individuals Kim et al. did not use the method of contrasting between L1 and L2, as it was done in our study. They were measuring the areas of maximal activity within the inferior frontal gyrus and comparing the distances between them. Nevertheless, the conclusions made by Kim et al. [12] are comparable to the results obtained by us, because they confirmed the influence of the foreign language acquisition age on the cortical language representation as well. The recently published study results also confirm the influence of the acquisition age on the patterns of language area activation [24].

Conclusions

The results of the study confirm the influence of the acquisition age on the patterns of language area activation – areas connected with syntax mainly. Early age of acquisition allows for syntax acquisition at the level similar to the native one. More significant differences could be observed in areas connected with semantics. The LA group, on the other hand, revealed more pronounced differences between the L1 and L2 in the region connected with syntax.

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