Aud Vest Res (2016);25(2):127-134.

RESEARCH ARTICLE

Effect of bilingualism on volume of corpus callosum

Ehsan Negin[1], Saeid Farahani[1*], Shohreh Jalaie[2], Samaneh Sadat Barootian[1], Alireza Pourjavid[1], Maryam Eatemadi[1], Milad Kazemiha[3], Mojtaba Barzegar[4]

[1]- Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[2]- Biostatistics, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[3]- Department of Anatomy, School of Medicine, Iran University of Medical Sciences, Tehran, Iran

[4]- Department of Medical Physics, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran

Received: 28 Mar 2016, Revised: 8 Apr 2016, Accepted: 13 Apr 2016, Published: 18 May 2016

Abstract

Background and Aim: In spite of the effect of the left hemisphere domination on first language acquisition in human, studies suggest activities and the role of both hemispheres in learning second language. Therefore learning a second language requires more communication between the two hemispheres. Regarding the role of the corpus callosum as the only data-centric interface between the two hemispheres, the aim of this study was to evaluate and compare the volume of the corpus callosum in monolingual and bilingual individuals.

Methods: This cross-sectional study was conducted on 24 samples, 16 simultaneous bilinguals (eight Kurdish-Persian, eight Turkish-Persian) and eight monolinguals with age range of 18 to 30 years, all right handed, and in equal numbers in both sexes (female and male), volume of corpus callosum determined by MRI. Data was analyzed by parametric and non-parametric statistical tests.

Results: The volume of corpus callosum is smaller in monolinguals in comparison with bilinguals, in which a significant difference was observed (p=0.04).

Conclusion: According to the language data transmission and the rate of processing by the corpus callosum between two hemispheres, it seems for improving the quality of aural rehabilitation, the findings of present study will be useful before performing programs like auditory training, language learning, and by development of neuroplasticity which is often decoded by stimulus that occur in the hemisphere in contrast to the dominant hemisphere.

Keywords: Corpus callosum; bilingualism; neuroplasticity

[*] **Corresponding author:** Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Piche-Shemiran, Enghelab Ave., Tehran, 1148965141, Iran. Tel: 009821-77533939, E-mail: s_farahani@tums.ac.ir

Introduction

There are several studies on second language structural effects on anatomical and physiological features of the brain. Brocca was the first researcher that talked about of the left hemisphere of the human brain as the dominant hemisphere in language processing. According to his results, this phenomena was observed in 90-95% of the right handers and 70% of the left handers [1]. Other studies have been conducted by using medical imaging techniques; they believe that in the language-learning process and after evolution of auditory memory, another important factor is lateralization. Based on this hypothesis, learning first language (L1) after a while transfers from right hemisphere to left hemisphere and remains in this side until the

end of life [2].
Recent investigations show that in bilingual people, in addition to special area activity in left hemisphere in the meantime of the first language processing (L1), there are also other specific areas in the right hemisphere which have a very important and effective role in the second language (L2) processing. The f-MRI findings confirm that learning L2 mainly occurs in both hemispheres. It is obvious that right hemisphere activities are more related to the second language than to the first language [3]. Among the hypotheses, about L2, the simultaneous utilization of the both hemispheres is important in the processing of the second language [3]. The main point is the high functionality of communication between both hemispheres in language switch, which has direct effect on processing ability of L2. Certainly primary auditory cortices of right and left hemispheres have no direct relation to each other but corpus callosum acts as a connector between them. In response to learning and using it, the human brain makes adaptations preparing multi-lingualism. These adaptations can appear in the form of reinforcement in the areas of first language [3-9], or by formation of new neural cortical networks in specific areas in cortex [10-14].
Corpus callosum is the main conduit for information flowing between two hemispheres, which is made of axonal fibers. It is said that, there are 200 to 300 million axons in corpus callosum [15-17]. Up to now lots of studies have been done about the connector between two hemispheres and corpus callosum, that show effects of genetic and pathological factors such as handedness [18], sex [19], head traumas [20], autism [21], multiple sclerosis [22], schizophrenia [23], Tourette syndrome [24], dyslexia [25], Attention deficit hyperactivity disorder (AD/HD) [26], learning disabilities [27], on the size of corpus callosum.
However, research on the nervous system neuroplasticity as a result of a second language function and simultaneous activities of the two hemispheres in L2 processing had been neglected. In the study that was conducted by Porter et al. [cited in 28] aiming for evaluation and investigation of the size of corpus callosum in monolinguals and bilinguals, but, in fact, they only evaluated two-dimensional size of corpus callosum.
In different studies, also, it has been shown that the size of corpus callosum is affected by factors such as a combination of experience, environment and genetics, and shows flexibility [29-32]. In an example, in the study conducted by Castro-Caldas et al. [33] it is explained that in literate women, the size of corpus callosum in the part of posterior mid-body in comparison with illiterate women is significantly larger.
In regards to this flexibility of nervous system, we can expect that following bilingualism and learning second language, and also cooperating two hemispheres in processing second language, causes increasing size of nervous fibers existing in some parts of corpus callosum. Therefore, this study aimed to investigate the volume of corpus callosum in Persian monolinguals and bilinguals (Kurdis and Turkis), with this research hypothesis that there is significant difference between monolinguals and bilinguals.

Methods
This cross-sectional study was conducted on 16 simultaneous bilinguals (eight Kurdish-Persian, eight Turkish-Persian) and eight monolinguals; all were right handed, age range 18 to 30 (mean and SD: 21.24, 1.7 year). Tests performed on audiology clinic (Audiology Department), School of Rehabilitation, Tehran University of Medical Sciences. The other inclusion criterias were having normal hearing thresholds, no history of head trauma, neurologic and otologic diseases. For avoiding interference of other factors which could affect hemispheric processing, none of cases were musician and painter. Some cases who showed no tendency to continue their cooperation, or claustrophobia (fear from being in MRI tunnel) were excluded.
At first we described the program process for cases who were willing to participate in this research, then they filled a form consenting to participate in this research. And completed case history form (including individual characteristics, way of language learning, mother language

as a first language and second language), place of birth, first and second language learning environment, and the manner of learning second language, too.
All of participants should complete the questionnaire about the bilingualism process. We must mention that all samples including Kurdish-Persian and Turkish-Persian bilinguals, first learned mother language. It is obvious that this process (L1 acquisition) has occurred for all bilinguals in natural learning ways. Also, in five or six year olds, due to preschool entry, they begin to learn L2 (Persian language), of course we should not ignore the role of media in Persian language learning in all samples from childhood. So, we can say that bilinguals in present study are mostly simultaneous bilinguals. They have been asked about English language learning; nearly all of them began to learn English after the age of 10. But we tried not to participate the people who are completely fluent in four English language skills (reading, writing, listening and speaking). Although researchers in this study believed that there are no change in results of research for bilinguals fluent in English, because changes will occur in right hemisphere activity. In monolingual participants none of them was perfect on all four skills.
In order to evaluate the health of peripheral hearing system, we performed pure tone audiometry (PTA) for all participants by using the clinical audiometer AC40, (Interacoustic, Denmark), and acoustic immittance audiometry by Zodiac (GN Otometrics, Denmark). The participants who met the inclusion criteria were determined right handed by Persian version of Edinburgh questionnaire. Finally the corpus callosum volume was measured by the technician who knew nothing about the project, by using the 3 Tesla magnetic resonance imaging (MRI) device (Simense, Germany) in Khatam-ol-Anbia hospital in Tehran.
For measuring the corpus callosum volume, the Image J software (Wayne Rasband, Maryland, USA) was used. This software was designed by National Health Institute, and is proven useful in areas such as hematology.
Slices with highest contrast of corpus callosum were chosen, in order to precise measuring and determining the best slice. Since these slices were stable in all samples thereby the software errors could be omitted in this way.
In order to determine the volume of corpus callosum, first borders of corpus callosum identified by the software, and then multiplied by the section thickness (3 mm), to obtain corpus callosum volume. Then total volume obtained by summating volume of corpus callosum in those slices which software could identified corpus callosum borders.
We used software to determine the borders of corpus callosum. This software by using the amount of contrast changing of corpus callosum with its adjacent areas in the white matter of the brain, which was imaged at a different slice, allows the possibility of determining the exact corpus callosum border. Fig. 1. Shows a sample of measuring and determining corpus callosum borders by software.
For describing the findings in total data and for subgroups in separate, mean and standard deviation were used. Normality of distribution in corpus callosum volume was tested by Kolmogrof-Smirnof test. For comparing the volume of corpus callosum between two groups, if they had the test assumptions, we used the parametric independent t-test; otherwise nonparametric Mann-Whitney test was used.

Results

Twenty four cases take part in this study, 16 bilinguals (eight Kurdish-Persian and eight Turkish-Persian) and eight Persian monolinguals. The age range was 18 to 30 years old (mean and SD: 21.24, 1.7). The volume of corpus callosum was measured totally and in each subgroups separately (Table 1). The mean and standard deviation in females was 179928.33, 33528.5 respectively and in males 176876.4, 7242.02 respectively.
Although corpus callosum volume has normal distribution in monolinguals and all bilinguals separately, there was no normal distribution in Persian-Turk participants. Independent t-test shows the mean of corpus callosum volume (mm^3) in bilingual is Significantly larger than

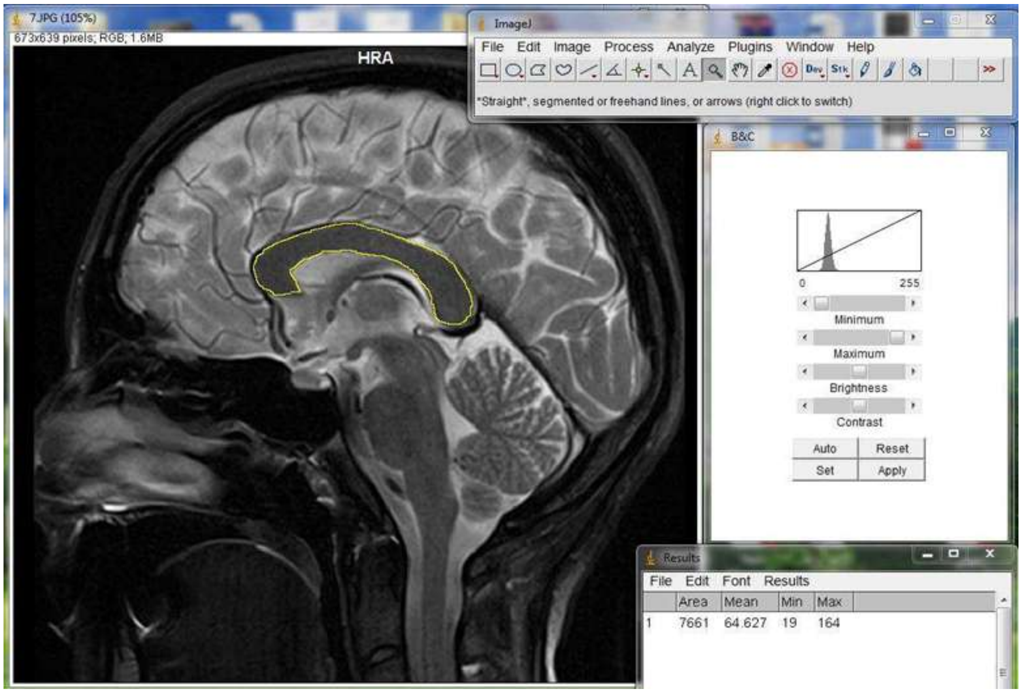

Fig.1. Sample of measurement and determination of corpus callosum border by software.

monolingual (p=0.04), with 95% confidence interval (-882.8, 58853).

Between two bilingual groups, due to abnormality in the Turk group, for comparing Persian-Turk and Persian-Kurd groups, nonparametric Mann-Whitney is used. No significant difference observed in results (p=0.959), see Table 1.

To compare corpus callosum volume between sex, regardless of monolingual or bilingual, independent t-test was used, as we compare the mean of corpus callosum volume between 12 female and 12 male (Fig. 2), which it showed no significant difference (p>0.05).

Discussion

Finding of this research represents that bilingualism may affect the total volume of the corpus callosum. It seems that brain processing following the organization after multilingualism in cortex, needs to increase homotopic relationship between the two hemispheres.

The results of this study are consistent with the results of Dehaene et al. [10], Gomez-Tortosa et al. [11]; Kim et al. [8]; Paulesu et al. [12]; Perani et al. [13]; Rodriguez-Fornells et al. [14]; Simos et al. [9]. These researches believe that second language input, leads to the formation of new neural networks in the brain. Dimond et al. mentioned that, it is likely that the corpus callosum has an effect on language processing [34]. Of course today, these findings according to data obtained based on f-MRI from researches, is not totally accepted, but it seems by the role of this brain region in transfering the language data between two hemispheres and activity of hemispheres in bilingualism, the data transfer rate between the two hemispheres, because of myelination of axons of corpus callosum will be increased. Albert and Obler [35] reported that, bilaterality is more in bilinguals than monolinguals.

A study was conducted on language laterality and its effect on the corpus callosum by Westerhausen et al. [36], they performed this research on 89 participants by using f-MRI and investigated the relationship between two hemispheres. Their results showed no significant difference in the size of corpus callosum. It seems that the main reason of difference between their results and our findings are due to the lack of

Table 1. Measures of central tendency and statistical dispersion of corpus callosum volume (mm^3) in different language and sex groups

Group		Male				Female			
		Mean (SD)	Median	Minimum	Maximum	Mean (SD)	Median	Minimum	Maximum
Bilingual	Kurdish-Persian	187478.50 (48966.52)	202673.0	116472.00	228096.00	185268.75 (34702.74)	189675.00	141597	220128
	Turkish-Persian	177425.25 (45619.75)	195445.5	109860	208950	203261.5 (19462.27)	195775.5	189805.00	231690.00
Mono lingual	Persian	165725.5 (17047.06)	165446.00	145797	186213	151254.75 (26051.61)	143139	130494	188247

attention to handedness and hemispheric dominance. In their study the participants were in both from right handed and left handed groups, therefore hemispheric dominant interference could affect the results. Also, they did not measure the volume of corpus callosum and only the size of the corpus callosum was considered. Vaid and Lambert [37], Sussman et al. [38] believe that right hemisphere activity is more in bilinguals than in monolinguals.

Thereby, in Barton et al. [39] study there was no difference between English monolinguals and English-Hebrew bilinguals. Also, Tzeng et al., compared English-Chinese bilinguals with Chinese monolinguals, and results revealed no significant difference in speech recognition score [40].

The reason of different and large extent of findings might be due to factors such as age of onset of bilingualism and level of dominance to second language [41].

The important difference in this study with similar studies is the exact determination of corpus callosum volume. In present study, researchers believe that regarding the brain growth in all three dimensions, only measuring the size of corpus callosum in two-dimensional MR image, could not demonstrate real corpus callosum volume. Therefore in addition to preserving measure of two-dimensional image of corpus callosum, measuring of corpus callosum volume was considered in our study and the results were investigated.

In present study the selected bilinguals were fluent in both languages. All bilinguals were fluent in all four language skills in both languages. This is very important in this study because the base of most researches is free of such important point. This point is so important that even with the addition of one of the skills rather than four language skills the results will surely be affected. For instance, Silverberg et al. [42] has reported that right hemisphere activity in the English-Hebrew bilingual children who were supported to learn for two years regarding reading of English language in comparing to children who were learning four to six years are less.

The results of present study almost confirm the Vaid findings. He reported that bilinguals who informally acquired second language (L2) from the environment, revealed more right hemisphere activity. So this study also regards that in informal learning, right hemisphere activity increases and consequently corpus callosum volume becomes bigger due to transferring more stimuli [43].

As mentioned, by learning second language and the activity of new sections in right hemisphere and remaining activity in left hemisphere, mostly both hemispheres are involved in the second language processing. This kind of process undoubtedly needs both hemispheres' effective relationship that mostly occurs from pathway of corpus callosum. According to the affirmation of the theory of neuroplasticity in corpus callosum, and increasing data transfer between two hemispheres, gradually over time, the

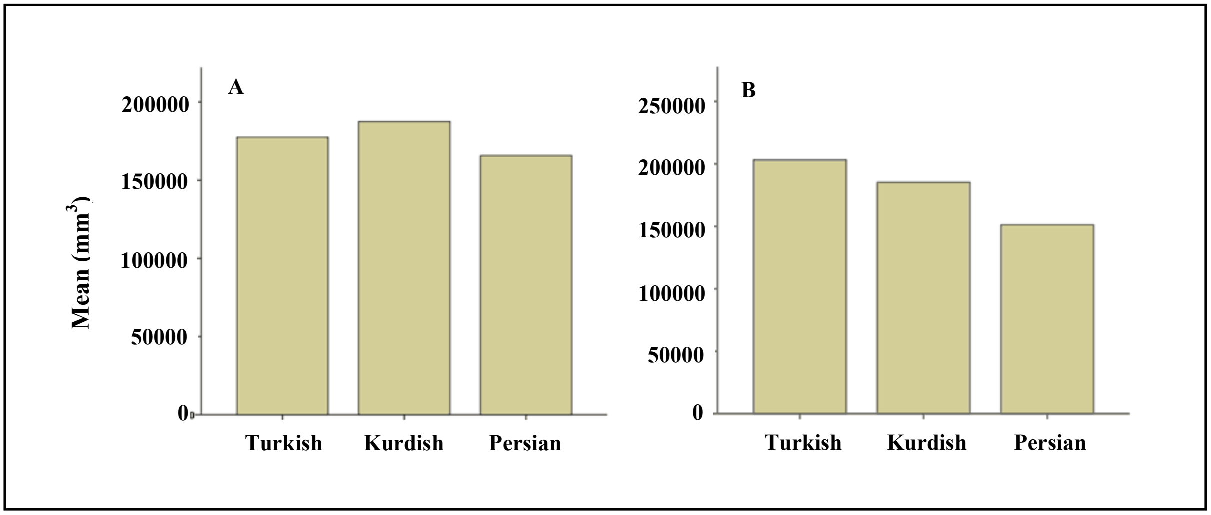

Fig.2. Mean corpus callosum volume (mm^3) in three language groups, A) male, and B) female.

flexibility of the nervous system occurs in corpus callosum and it shows increasing in the volume.

This study had some limitations; the most important one being high costs of MR imaging and no insurance covering and also image artifacts.

To reach better and more confident results we suggest conducting similar studies but in bigger size of participants. We do suggest for determining the kind of bilingualism, using questionnaire and precise case history as well, and it's better to examine the results on different kinds of bilingualism.

Conclusion

It seems due to receiving further input by bilingualism, also the role of right hemisphere in learning second language, the neuroplasticity of bilingualism in these people by connecting left and right hemisphere, has caused increasing on total corpus callosum volume. According to the role of corpus callosum on language, data transferring specially in bilinguals, the rate of processing of data which alternates between the two hemispheres, also in hemispheric function, it seems, in order to improve the quality of auditory rehabilitation (before performing programs like auditory training, rehabilitation of central auditory processing disorder (CAPD) and language learning, with development in the flexibility of the nervous system which is often decoded by stimulus occurrence in the hemisphere in contrast to the dominant hemisphere), would be useful. So we can expect an improvement in rehabilitation programs following the increase of the processing rate. Most of the rehabilitation programs build up with the aim to improve incomplete brain activity through the flexibility of the nervous system. Researches in this study suggest that according to the role of the two hemispheres processing in data transfer rate during the time, rehabilitation programs should be designed in such a way that flexibility of the nervous system in that program is in a parallel role rather than serial. Also this is an important point to be investigated in a separate research.

Acknowledgements

This study was supported by Tehran University of Medical Sciences with grant number 268-20-32-01-92. The authors wish to acknowledge of the sincere cooperation of personnel of the Khatam ol Anbia.

REFERENCES

1. DE Groot AMB. Language and cognition in bilinguals and multilingual. 1st ed. New York: Psychology press; 2011.
2. Obler L. Right hemisphere participation in second language acquisition. In: Diller KC, editor. Individual differences and universals in language learning aptitude. 1st ed. Newbury House; 1981. p. 53-64.

3. Chee MW, Tan EW, Thiel T. Mandarin and English single word processing studied with functional magnetic resonance imaging. J Neurosci. 1999;19(8):3050-6.
4. Hasegawa M, Carpenter PA, Just MA. An fMRI study of bilingual sentence comprehension and workload. Neuroimage. 2002;15(3):647-60.
5. Hernandez AE, Dapretto M, Mazziotta J, Bookheimer S. Language switching and language representation in Spanish-English bilinguals: an fMRI study. Neuroimage. 2001;14(2):510-20.
6. Illes J, Francis WS, Desmond JE, Gabrieli JD, Glover GH, Poldrack R, et al. Convergent cortical representation of semantic processing in bilinguals. Brain Lang. 1999;70(3):347-63.
7. Keller TA, Carpenter PA, Just MA. The neural bases of sentence comprehension: a fMRI examination of syntactic and lexical processing. Cereb Cortex. 2001;11(3):223-37.
8. Kim KH, Relkin NR, Lee KM, Hirsch J. Distinct cortical areas associated with native and second languages. Nature. 1997;388(6638):171-4.
9. Simos PG, Castillo EM, Fletcher JM, Francis DJ, Maestu F, Breier JI, et al. Mapping of receptive language cortex in bilingual volunteers by using magnetic source imaging. J Neurosurg. 2001;95(1):76-81.
10. Dehaene S, Dupoux E, Mehler J, Cohen L, Paulesu E, Perani D, et al. Anatomical variability in the cortical representation of first and second language. Neuroreport. 1997;8(17):3809-15.
11. Gomez-Tortosa E, Martin EM, Gaviria M, Charbel F, Ausman JI. Selective deficit of one language in a bilingual patient following surgery in the left perisylvian area. Brain Lang. 1995;48(3):320-5.
12. Paulesu E, McCrory E, Fazio F, Menoncello L, Brunswick N, Cappa SF, et al. A cultural effect on brain function. Nat Neurosci. 2000;3(1):91-6.
13. Perani D, Dehaene S, Grassi F, Cohen L, Cappa SF, Dupoux E, et al. Brain processing of native and foreign languages. Neuroreport. 1996;7(15-17):2439-44.
14. Rodriguez-Fornells A, Rotte M, Heinze HJ, Nösselt T, Münte TF. Brain potential and functional MRI evidence for how to handle two languages with one brain. Nature. 2002;415(6875):1026-9.
15. Aboitiz F, Scheibel AB, Fisher RS, Zaidel E. Fiber composition of the human corpus callosum. Brain Res. 1992;598(1-2):143-53.
16. Nolte J. The human brain: an introduction to its functional anatomy. 4th ed. St. Louis: Mosby-Year Book, Inc; 1998.
17. Tomasch J. Size, distribution, and number of fibres in the human Corpus Callosum. Anat Rec. 1954;119(1):119–35.
18. Witelson SF. Hand and sex differences in the isthmus and genu of the human corpus callosum. A postmortem morphological study. Brain. 1989;112 (Pt 3):799-835.
19. Patricia E. Cowell, size differences in the callosum: analysis beyond the main effects. In: Zaidel E, Lacoboni M, editors. The parallel brain- the cognitive neuroscience of corpus callosum. 1st ed. Massachusetts: MIT Press; 2003. p. 64-9.
20. Benavidez DA, Fletcher JM, Hannay HJ, Bland ST, Caudle SE, Mendelsohn DB, et al. Corpus callosum damage and interhemispheric transfer of information following closed head injury in children. Cortex. 1999;35(3):315-36.
21. Egaas B, Courchesne E, Saitoh O. Reduced size of corpus callosum in autism. Arch Neurol. 1995;52(8):794-801.
22. Gean-Marton AD, Vezina LG, Marton KI, Stimac GK, Peyster RG, Taveras JM, et al. Abnormal corpus callosum: a sensitive and specific indicator of multiple sclerosis. Radiology. 1991;180(1):215-21.
23. Jacobsen LK, Giedd JN, Rajapakse JC, Hamburger SD, Vaituzis AC, Frazier JA, et al. Quantitative magnetic resonance imaging of the corpus callosum in childhood onset schizophrenia. Psychiatry Res. 1997;68(2-3):77-86.
24. Peterson BS, Leckman JF, Duncan JS, Wetzles R, Riddle MA, Hardin MT, et al. Corpus callosum morphology from magnetic resonance images in Tourette's syndrome. Psychiatry Res. 1994;55(2):85-99.
25. Hynd GW, Hall J, Novey ES, Eliopulos D, Black K, Gonzalez JJ, et al. Dyslexia and corpus callosum morphology. Arch Neurol. 1995;52(1):32-8.
26. Hynd GW, Semrud-Clikeman M, Lorys AR, Novey ES, Eliopulos D, Lyytinen H. Corpus callosum morphology in attention deficit-hyperactivity disorder: morphometric analysis of MRI. J Learn Disabil. 1991;24(3):141-6.
27. Njiokiktjien C, de Sonneville L, Vaal J. Callosal size in children with learning disabilities. Behav Brain Res. 1994;64(1-2):213-8.
28. Coggins PE, Kennedy TJ, Armstrong TA. Bilingual corpus callosum variability. Brain Lang. 2004;89(1):69-75.
29. Innocenti GM, Frost DO. Effects of visual experience on the maturation of the efferent system to the corpus callosum. Nature. 1979;280(5719):231-4.
30. Juraska JM, Kopcik JR. Sex and environmental influences on the size and ultrastructure of the rat corpus callosum. Brain Res. 1988;450(1-2):1-8.
31. Schlaug G. The brain of musicians. A model for functional and structural adaptation. Ann N Y Acad Sci. 2001;930:281-99.
32. Schlaug G, Jäncke L, Huang Y, Staiger JF, Steinmetz H. Increased corpus callosum size in musicians. Neuropsychologia. 1995;33(8):1047-55.
33. Castro-Caldas A, Miranda PC, Carmo I, Reis A, Leote F, Ribeiro C, et al. Influence of learning to read and write on the morphology of the corpus callosum. Eur J Neurol. 1999;6(1):23-8.
34. Dimond SJ, Scammell RE, Brouwers EY, Weeks R. Functions of the centre section (trunk) of the corpus callosum in man. Brain. 1977;100(3):543-62.
35. Albert ML, Obler LK. The bilingual brain: neuropsychological and neurolinguistic aspects of bilingualism. 1st ed. New York: Academic Press; 1978.
36. Musálek M. Development of test batteries for diagnostics of motor laterality manifestation: link between cerebellar dominance and hand performance. 2nd ed. Prague: Karolinum Press; 2014.
37. Vaid J, Lambert WE. Differential cerebral involvement in the cognitive functioning of bilinguals. Brain Lang. 1979;8(1):92-110.
38. Sussman HM, Franklin P, Simon T. Bilingual speech: bilateral control? Brain Lang. 1982;15(1):125-42.
39. Barton MI, Goodglass H, Shai A. Differential recognition of tachistoscopically presented English and

Hebrew words in right and left visual fields. Percept Mot Skills. 1965;21(2):431-7.
40. Tzeng OJ, Hung DL, Cotton B, Wang WS. Visual lateralisation effect in reading Chinese characters. Nature. 1979;282(5738):499-501.
41. Hamers JF, Blanc MHA. Bilinguality and bilingualism. 2nd ed. Cambridge: Cambridge University Press; 2000.
42. Silverberg R, Bentin S, Gaziel T, Obler LK, Albert ML. Shift of visual field preference for English words in native Hebrew speakers. Brain Lang. 1979;8(2):184-90.
43. Vaid J. Bilingualism and brain lateralization. In: Segalowitz SJ, editor. Language functions and brain organization. New York: Academic Press; 1983. p. 315-39.