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Audio-linguistic functioning of children bilaterally implanted with cochlear implants in the sequential mode, a preliminary report

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Severe hearing damage in the prenatal period or when the baby is born is a disability that significantly impairs the correct functioning in the society of hearing people. A particularly perceptible consequence of severe hearing impairment is the lack or significant delay in the development of speech and language acquisition. Thanks to the use of cochlear implants, the Program Chirurgicznego Leczenia Głuchoty Metodą Wszczepów Ślimakowych [Program of Surgical Treatment of Deafness With the Method of Cochlear Implantation] allows children with *perceptive* deafness for the access to speech sounds through the auditory pathway. It gives them an opportunity to develop speech and language and in the future – the ability to satisfactorily communicate with other people. The study covered 54 born-deaf children, bilaterally implanted in the sequential mode. The implantation was performed at the Department of Otolaryngology and Laryngological Oncology of the *Poznan University of Medical Sciences*. The results indicate a constant, dynamic increase of auditory and linguistic-communication skills in the examined group.

KEY WORDS: audio-linguistic skills, deaf children, bilateral implantation with cochlear implants in the sequential mode

Introduction

Efficient hearing is one of the senses used by a child to explore the reality. It is a tool by which we can discover language and learn to communicate with other people. Proper hearing is responsible not only for the perception of speech through the auditory pathway and understanding of direct and indirect messages, but also for the control of our vocal production. Already in the foetal life, in the process ontogenesis – the child's brain is „prepared to pay attention" to human speech. Then, in the first few months of a child's life, listening to the sounds of the language that other people communicate through is sufficient to develop nerve structures responsible for the ability to understand and create functional language constructions.[1] Severe hearing impairment in the *prelingual* period is a very serious disability. It can limit interactions with other people and consequently prevent the child from the full, harmonious development.

The lack of development of the language used for communication and building the „inner speech" increases the processes of information deprivation, leading to cognitive deficits. The emerging social difficulties and psycho-emotional problems connected with the inability to interpret the world and attitudes of people from the nearest proximity can cause in a child and later in a young, deaf person – the feeling of isolation, alienation, anxiety and withdrawal. Therefore, it is important to detect and diagnose hearing loss and hearing disorders as early as possible in order to minimize the negative consequences of functional limitations. A rapid diagnosis and medical intervention, which provide the child with hearing aids, give an opportunity to initiate rehabilitation before the end of a period which is critical to the development of a given function, i.e., the period of maximum susceptibility and plasticity of the nervous system to certain environmental stimuli. The first years of a child's life are the basis for the future psycho-motor and emotional

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[1] A. Smith, „*Umysł*" PZWL, Warsaw 1989, pp. 121-125.

development; this time is also important for the acquisition of speech and language. A cochlear implant may be used when the hearing defect is so great that classic hearing aids will not allow for the sufficient perception of hearing sounds through the auditory pathway. The Program Chirurgicznego Leczenia Głuchoty Metodą Wszczepów Ślimakowych is dedicated to people with severe bilateral *perceptive* deafness. Obliteration of the cochlea and anatomical anomalies of the inner ear, which can be detected only by specialist examinations, such as computed tomography or magnetic resonance imaging, are contraindications for implantation. A cochlear implant allows for the reception of sounds, like speech from the environment, and through acoustic-electrical stimulation provides stimuli to the auditory centres of the central nervous system where they are received as auditory sensations.[2] An efficient brain learns to interpret and give meaning to these stimuli. If the sensory access to speech and language through the auditory pathway is practically impossible, a cochlear implant gives children with *prelingual* deafness an opportunity to detect, differentiate, distinguish, identify and finally understand speech sounds. However, the use of this technique is not sufficient for the child to independently develop auditory and verbal skills. Systematic, planned therapy, which is based on hearing education, is necessary. Hoping that this surgical method will give the child an opportunity to discover a world rich in acoustic experience, parents usually quickly make a decision to provide a deaf child with a cochlear implant. They also hope that this way the child will get a chance to „be normal", just like its peers. The popularization of the knowledge that the need for rapid implantation, performed as early as possible, enables a hearing-impaired child to develop just like normally hearing children, often makes that their parents take a decision quickly, guided by emotions, with no specific expectations for the implant and the entire postoperative rehabilitation process. Therefore, there can be deep

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[2] H. Skarżyński, *Wszczepy ślimakowe,* [in:] *Zarys audiologii klinicznej,* edited by A. Pruszewicz, Poznan 2000, 2, p. 517.

disappointment when the cochlear implant does not miraculously restore hearing, and the process of acquiring listening and verbal skills is very tedious and does not always bring the expected results.

In this situation, parents of unilaterally implanted children begin to consider the possibility of implanting a second prosthesis. In the Department of Otolaryngology of the *Poznan University of Medical Sciences*, a decision on bilateral implantation is made taking into account medical indications: other dysfunctions (for instance, Usher syndrome or a severe visual defect) and, for example, the lack of notable benefits of using a single prosthesis. This decision causes different dilemmas among parents: whether to provide a second implant to a child with very good hearing and speech function in the first prosthesis, or rather support with a second implant a child, that for a variety of reasons, does not benefit from the first prosthesis? Scientific studies conducted in numerous implant centres around the world clearly indicate that, when the conditions for proper treatment are met, children with cochlear implants are able to understand speech in open sets only through the auditory pathway and the functional language develops sufficiently to ensure communication.[3] Bilateral implantation can further enhance speech comprehension in acoustically difficult conditions, allows for the accurate localization of sounds and improves the quality of spatial hearing.[4] Improving the comfort and quality of „binaural" hearing in two cochlear implants opens new possibilities for users of the system. For a young child, who is probably inexperienced in auditory sensations, the newly acquired abilities are invaluable and can positively influence the level of socialization and the quality of everyday life. Bilateral implantation can be simultaneous when two implants are introduced at the same time, and this usually applies

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[3] B. Szagun, *The acquisition of grammatical and lexical structures in children with cochlear implants: a development psycholinguistic approach,* "Audiol Neurootol", 2000, 5, pp. 39-47.

[4] J. Sarant, D. Harris, L. Bennet, S. Bant, *Bilateral versus unilateral cochlear implants in children: a study of spoken language outcomes,* „Ear Hear", 2014 Jul.-Aug., 35(4), pp. 396-409.

to patients after meningitis or in other medically justified cases. Under Polish conditions, implantation in the sequential mode is the most common form performed within the Program Chirurgicznego Leczenia Głuchoty Metodą Wszczepów Ślimakowych, which means that a minimum of one year has to elapse from an operation to a decision to perform another surgery. This decision is made by a team of specialists taking into account the results of psychological-pedagogical-speech therapy tests, individual predispositions and medical indications.

Material and Methods

The study included 54 children with *prelingual* deafness, bilaterally implanted in the sequential mode. The first and second cochlear implantation were performed in the Department of Otolaryngology and Laryngological Oncology of the Karol Marcinkowski *Poznan University of Medical Sciences*. All examined children had used hearing aids until the moment of implantation. Spontaneous vocal productions, which were observed in approximately 30% of subjects before the first operation, were not reflected in the linguistic system. All examined children had *normal intellectual* capacity, three children were diagnosed and later confirmed with autism spectrum disorder and four children had a serious defect of vision. The study group of bilaterally implanted children was homogeneous and used the Nucleus cochlear implant by Cochlear. All children were brought up in families of hearing people who used sound speech on a daily basis. The study group was provided with the first implant between 18 months and 5 years of age. At the time of the study, children differed in terms of physiological age: 70% were between 7 and 10 years of age, and the remaining 30% were between 10 and 18 years of age.

The children were provided with regular speech therapy at their place of residence, i.e. at school they attended to or in the immediate vicinity. The total duration of the use of one implant, which is equiva-

Table 1. The duration of the cochlear implant use in all patients – unilateral implantation

The duration of the use of a single cochlear implant	Number of patients
From 2 to 7 years	33
From 7 to 12 years	15
More than 12 years	6

Table 2. The duration of the simultaneous use of two cochlear implants (from the moment of the second implantation) – bilateral implantation in the sequential mode

The duration of the use of two cochlear implants	Number of patients
From 18 months to 3 years	30
From 3 to 5 years	21
More than 5 years	3

lent to postoperative rehabilitation time, ranged from two to seventeen years (Table 1), and the time that elapsed between the first and second implantation was a minimum of one year and a maximum of thirteen years. The duration of the simultaneous use of two active cochlear implants ranged from eighteen months to even six years (Table 2). The study used the TAPS (Test of Auditory Perception of Speech), translated and adapted to the conditions of the Polish language in the Department of Otolaryngology of the *Poznan University of Medical Sciences* and in the Department of Acoustic Phonetics of the Polish Academy of Sciences in Poznan. The test gives an opportunity to check how the child hears and understands spoken sounds in closed and open sets. The study was conducted under difficult acoustical conditions, in the presence of disturbing sounds. The children performed test tasks when using one (the second implant was inactive) and two active implants. In all patients, hearing maps, which were generated during the speech processor programming session, were stable. In addition, the Arkusz Badania Umiejętności

Językowych [Language Skills Test Sheet], which was created at the centre in Poznan, was used in the study. The sheet examines basic language skills in terms of understanding, speech production, conceptual resources and phonological awareness, which is necessary to create correct vocal articulation patterns.

Results

All the children who use the system for a minimum of time – flawlessly perform the *phoneme perception test* through the auditory pathway – both with one and two implants. The results of the TAPS-level II also show that all the patients, who already function in one implant, have mastered the perception of rhythmic speech patterns through the auditory pathway in the presence of disturbing sounds, and this is necessary to develop the ability to distinguish and differentiate suprasegmental speech components – both heard and those produced by oneself (Table 3). The results of the previous studies indicate that children need for this process about six months on average.[5] Only patients with coexisting developmental deficits, which may delay the formation of cognitive schemas, require a little more time to complete this process – about one to two years.[6]

Table 3. TAPS, level III (listening in noise)

Implanted patients	Perception of rhythm speech patterns
Listening with one implant	100%
Listening with two implants	100%

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[5] W. Szyfter, A. Pruszewicz et al., *Ocena zachowań słuchowych dzieci posługujących się wszczepem ślimakowym,* „Otolaryngologia Polska", 1997, Volume L, Supplement 22, pp. 200-204.

[6] W. Szyfter, J. Kaczmarek et al., *Czy mnogie uszkodzenia uniemożliwiają zastosowanie wszczepów wewnątrzślimakowych,* „Rehabilitacja w Otologii", [in:] Conference materials, Poznan 8-10.10.1998.

Table 4. TAPS, level III (listening in noise)

Perception of speech features, speech identification	Number of patients – listening with 1 implant			Number of patients – listening with 2 implants		
	CI usage time			CI usage time		
	From 2 to 7 years	From 7 to 12 years	More than 12 years	From 18 months to 3 years	From 3 to 5 years	More than 5 years
70% >	20	15	6	25	21	3
50%	11	–	–	5	–	–
50% <	2	–	–	–	–	–

Table 5. TAPS, level IV (listening in noise)

Recognition, understanding of speech, closed sets	Number of patients – listening with 1 implant			Number of patients – listening with 2 implants		
	CI usage time			CI usage time		
	From 2 to 7 years	From 7 to 12 years	More than 12 years	From 18 months to 3 years	From 3 to 5 years	More than 5 years
70% >	20	14	6	22	20	3
50%	10	1	–	7	1	–
50% <	3	–	–	1	–	–

Table 6. TAPS – level IV (listening in noise)

Recognition, understanding of speech, open sets	Number of patients – listening with 1 implant			Number of patients – listening with 2 implants		
	CI usage time			CI usage time		
	From 2 to 7 years	From 7 to 12 years	More than 12 years	From 18 months to 3 years	From 3 to 5 years	More than 5 years
70% >	20	14	6	22	19	3
50%	10	1	–	6	2	–
50% <	3	–	–	2	–	–

Table 7. Language Skills Test Sheet

Linguistic-communication skills	Number of patients – listening with 1 implant			Number of patients – listening with 2 implants		
	CI usage time			CI usage time		
	From 2 to 7 years	From 7 to 12 years	More than 12 years	From 18 months to 3 years	From 3 to 5 years	More than 5 years
Understanding	58%	70%	90%	56%	70%	90%
Speech production	53%	65%	75%	60%	70%	75%
Conceptual resources	45%	60%	70%	58%	65%	72%
Articulation	65%	80%	85%	70%	75%	90%

The results obtained in the next part of the TAPS test, level III, perception of speech traits and speech identification – show that bilaterally implanted children, with the duration of the implant use – even 18 months, achieve a bit better results in language tasks they hear in artificially generated noise with the intensity of about 40 dB. The longer the time of functioning with two implants, the more similar the results of listening in children with both active implants become (Table 4). The study revealed that the identification of words/phrases with the same number of syllables through the auditory pathway was the most difficult for the children. In this case, the role of guessing was not as important as the level of linguistic competence, which represented the active „functioning in the language". Once again, the longer duration of the implant/implants use, the better the results in this respect. This was evident at the level IV of the TAPS when children were expected to recognize and understand speech provided in closed and open sets (Table 5, 6). Reception and interpretation of the tested material at this level requires both passive knowledge and the active use of the functional language in all aspects: semantic, syntactic, morphological and phonological. The results reveal disproportions between hearing and understanding with one and two implants. With the use of two implants over 3 years, bilaterally implanted patients achieved the best results in this test category, heard in conditions analogous to the other stages – that is, acoustically difficult, in the presence of disturbing factors. The analysis of the remaining results from the Language Skills Test Sheet examination shows that this group of bilaterally implanted children using implants five or even more years achieves the best results in all tested spheres of the linguistic functioning (Table 7). The analysis of the results obtained by individual researchers demonstrates that the greatest delays occur in the sphere of speech production. In order to satisfactorily communicate with others, it is necessary to use language models that are appropriate for a given social situation and which should be creatively modified based on the knowledge of grammatical rules. Vocabulary chosen and used in specific situations results from conceptual resources that individual patients possess. It can also be observed that in the above-mentioned sphere children who use two implants for a long time (at least 4 years) achieve a slightly better outcome while listening compared to those with one implant. The extensive conceptual resources result from correct interpretation of the reality, while the lack of possibility to analyze co-existing acoustic characteristics (connected with different duration of deafness in individual patients) – objects, people, animals and various phenomena, can impair the process of the formation of concepts, and cause further difficulties and delay of the speech and language development. Patients with one and two implants obtained comparable results in the presented test tasks – in the area of articulation skills. This may be due to the fact that in many institutions the treatment of implanted patients is still performed by general speech therapists who are best prepared to work with patients requiring the correction of speech deficits at the level of proper articulation patterns. These interactions provide greater clarity of speech that is more understandable to others, however, such therapy has little to do with the overall *surdologopedic* effect in the linguistic-communication sphere. The results of the study show that children provided with two implants achieve better hearing outcomes than those with one implant. Linguistic skills are acquired in the course of systematic rehabilitation, but the final result also depends on the child's hearing age, the level of cognitive ability and motivation to speak. The availability to the long-term access to the spoken language through the auditory pathway – supported by the functioning with two implants, gives an opportunity to minimize the phonetic barrier that children with *prelingual* deafness have to overcome due to their disability.[7] The increased ability to improve sound localization and better understanding of speech in noise due to bilateral implantation further encourage children to use their linguistic skills in the group of peers, reduce anxiety associated with communication in uncomfortable acoustic conditions, and give them the conviction that they can understand and be understood by others. The children are more likely to initiate contacts based on linguistic communication and do better in situations where a rapid lingual response to hearing stimuli is required.

Discussion

The analysis of the study results shows that children who use two implants simultaneously achieve better hearing and verbal outcomes in acoustically uncomfortable situations than those staying in the same environment and having only one implant. The duration of the implant use also has a considerable impact on the level of individual linguistic competencies. The longer it is – the better the linguistic skills and the more extensive conceptual and vocabulary resources. If the child has two cochlear implants, there is binaural stimulation of the auditory pathway and hearing centres. This has a positive influence on the functioning in the acoustic environment and achieving better results in speech comprehension in all condi-

[7] Z.M. Kurkowski, *Mowa dzieci sześcioletnich z uszkodzonym słuchem,* Wydawnictwo UMCS, Lublin 1996, pp. 60-70.

tions and the consequent effective communication with others. The main goal of post-operative rehabilitation within the Program Chirurgicznego Leczenia Głuchoty Metodą Wszczepów Ślimakowych, is to stimulate the progress in all developmental spheres, with particular focus on the sphere of speech, language and hearing. The results of the studies conducted in similar centres around the world show that it is possible that the child with *prelingual* deafness and using a cochlear implant will acquire speech and language and will use these skills in interpersonal communication.[8]

Many linguists believe that each human has a genetically determined natural ability to master the linguistic processes and grammatical rules governing a given community.[9] However, the sensory access to sounds and consequently staying in the environment full of many acoustic and phonetic processes is a condition necessary to reveal this ability. A cochlear implant ensures the normal sound reception and perception, which, can not be guaranteed using classic hearing aids in severe hearing impairments developed in the *prelingual* period.[10] Early implantation gives a chance to develop hearing, speech and language in a natural manner and within physiological norms. The younger the child, the greater the chance of independent discovering and mastering of the language of the community in which the child grows.[11] Molina et al. have noted that the longer the duration of the implant use and post-operative rehabilitation, the greater the ability to apply the information provided

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[8] A. E. Geers, *Speech and language evaluation in aided and implanted children,* „Scand. Audiol.", 1997, 26, pp. 72-75.

[9] I. Kurcz, *Psychologia języka i komunikacji,* WSiP, Warsaw 2000; Shugar G., *Dziecko uczestnikiem dialogu w świetle badań z psycholingwistyki rozwojowej,* „Nowiny psychologiczne", 1996, p. 3.

[10] M. Kawczyński., W. Szyfter et al., *Postępy w rozwoju słuchowej percepcji mowy u dzieci zaimplantowanych wszczepem ślimakowym w różnych grupach wiekowych,* „Pediatria Polska", LXVII, No. 8, pp. 669-673.

[11] A.F.M. Snik, M.J.A. Makhdoum et al., The relations between age at the time of cochlear implantation and long term speech perception abilities in congenitally deaf subjects, "Int. J. Pediatr. Otorhin. Laryngol.", 1997, 52, pp. 214-217.

by the implant.[12] These observations coincide with the results obtained in children implanted in the centre in Poznan. Comfortable speech reception through the auditory pathway and understanding of heard information are conditioned by both the duration of the implant use and the quality of hearing with one and two implants. Sarant et al. notice a significant difference, in favour of bilaterally implanted children, in the quality of hearing in acoustically uncomfortable conditions, in which all hearing people exist and where the sounds overlap each other.

The results of the studies conducted among children implanted in the centre in Poznan coincide with the observations presented above.[13] Although the linguistic competencies of children bilaterally implanted in the sequential mode and using implants for a longer time (four years and more) usually deviate from the linguistic norm adopted for a particular physiological age in hearing children, they continue to develop dynamically. Two well-functioning cochlear implants ensure that the child will be able to hear and speak fluently – as good as possible – in every acoustic environment, in silence and in noise.[14]

Despite the high public awareness of the problem of deafness and its consequences, it is still necessary to educate people, because this may expand the knowledge provided to relatives who are interested in the Program Chirurgicznego Leczenia Głuchoty Metodą Wszczepów Ślimakowych. Parents of hearing-impaired children and deaf adults provided with reliable, substantive knowledge about the possibilities and limitations of using cochlear implants, will have an opportunity to make informed choices that can change their lives.

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[12] M. Molina, A. Huarte, Development of speech in 2- years- old children with cochlear implant, „Int. J. of Ped. Otorhinolaryngol.", 1999, 47, pp. 177-179.

[13] J. Sarant, D. Harris., Bilateral versus unilateral cochlear implants in children; a study of spoken language outcomes, „Ear Hear", 2914, Jul.-Aug.; 35(4), pp. 396-409.

[14] R.M. Reeder, J.B. Firszt et al., A longitudinal study in children with sequential bilateral cochlear implants: Time course for the Second Implanted Ear and Bilateral Performance", „J Speech lang Hear Res. 2017 Jan. 1, 60 (1), pp. 276-287.

Conclusions

1. The development of speech, language and auditory perception in children bilaterally implanted in the sequential mode is subject to the continuous improvement.

2. The level of development of speech and language competence is related to the duration of the cochlear implant use, among others.

3. Children bilaterally implanted in the sequential mode and using two efficient implants show better auditory orientation under different, not always comfortable, acoustic environments – than those using one implant under similar conditions.

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