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EFFECTIVENESS OF THE USE OF MINI-MICROPHONES FOR THE TREATMENT OF CHILDREN WITH COCHLEAR IMPLANTS – A MULTICENTER STUDY

The majority of children with hearing loss, thanks to screening programs, early fitting with hearing aids, and early therapeutic interventions, develop speech well enough to attend preschool along with their hearing peers. These preschool programs often take place in adverse acoustic conditions. In a study conducted on 25 children with hearing impairments aged 3 to 8 years (mean 5.9) – cochlear implant users – the therapeutic and educational effectiveness of the use of an additional hearing assistive device (mini wireless microphone) was tested. The results obtained confirmed the positive impact of the use of the device in additionally aiding hearing abilities in the areas of response to sound, sound localization, and quality of hearing.

Keywords**:** hearing impairment, hearing, hearing assistive technologies, mini-microphones, treatment of children with hearing impairments

Introduction

The changes that have been implemented in the education system, which were aimed at integration and are now moving towards inclusion, have ensured that more than 95% of children with hearing impairments attend mainstream preschools and schools (GUS, 2018). Hard-of-hearing and deaf children participate in the education process together with their hearing peers. This is for the benefit of both parties, based on the experience of settings that run inclusive education (Wereszka, 2017). It is worth considering integrating children with hearing impairments not only socially, but also educationally; that is, provide them with maximum comfort in gaining school skills with the minimum possible contribution of third parties. This will reduce their sense of otherness, special treatment, and may ensure that they feel autonomous. To get closer to this goal, we need to equip children with different types of hearing loss with the tools to cope in difficult situations, which is the task of families, psychologists, pedagogues, etc., and the best technical solutions to support their hearing, which is in turn the task of audiologists and audioprosthologists (Zaborniak-Sobczak, Bieńkowska, & Senderski, 2016, pp. 117–118; Zaborniak-Sobczak et al., 2018, pp. 116–117). An educational establishment is not the most favorable acoustic environment. As data from a report on noise in schools show (Augustyńska & Radosz, 2009, pp. 16–17), in most of the rooms in a school, noise exceeds the standards and makes it difficult or sometimes even impossible to understand speech by masking it. Noise not only adversely affects the health of teachers and students but also reduces the effectiveness of teaching which is based on the correct reception of verbal messages by students (Wilczyńska, Paciej, & Hudzik, 2012, pp. 890–891).

Meanwhile, what matters in the process of speech development is the amount and quality of auditory information reaching the central auditory fields responsible for encoding and decoding language information (Hart & Risley, 1995; Robinson, 1998, p. 78). For children with various types of hearing loss (including central auditory processing disorder), what is important is not only the quality of the amplification of the stimulus but also the efficiency of the auditory pathway and central auditory processes responsible for, among others: sound localization and lateralization, distinguishing the characteristics of a signal (auditory discrimination), recognition of the characteristics of auditory patterns, temporal aspects of audition, including: resolution, temporal analysis, temporal integration, and temporal ordering, the ability to receive a signal among competing acoustic signals (e.g., in a noisy environment), and the ability to receive signals of increased redundancy (ASHA, 1996).

What is important for the development of auditory perception and speech in children with hearing impairments in mainstream preschools and schools, therefore, is not only hearing with their primary hearing assistive devices used for hearing loss but also the usability and effectiveness of auxiliary equipment. Primary hearing assistive devices (hearing aid, cochlear implant) are sometimes insufficient to fulfil all of a child's auditory needs (Domagała-Zyśk, 2013, pp. 86–87). The biggest limitations concern hearing in noisy and reverberant rooms, which change acoustic waveforms, and the large distance between the sender and the deaf student. The most difficult situation, which is not very rare, happens when all these factors overlap (Crandell, Smaldino, & Flexer, 2004). In such situations, hearing assistive devices (in this case, improving hearing with hearing aids or a cochlear implant) can help. They represent different types of technical solutions used along with the primary devices by people with hearing impairments; they improve the quality of the sound heard and understanding of speech in difficult acoustic situations (background noise, noise, reverberation) as well as 'shorten' the distance between the sender and the receiver, i.e., they eliminate additional ambient sounds that often disrupt understanding. These are difficulties in the face of which a hearing aid or cochlear implant may not benefit the wearer. The operation of such devices consists in the use of a microphone that is close to the speaker (or a different sound source), thanks to which sound without distortion or any features of the acoustic environment is received by the hearing aid or cochlear implant (Flexer & Cole, 2015). There are several types of devices available: wired or – more frequently now – wireless devices that further amplify sound. They can be worn all the time along the primary equipment or at a time chosen by the patient (e.g., during telephone conversations or walks). In a classroom where more than one child with a hearing defect is being taught, inductance loops can be used for example.

Until recently, wireless assistive devices were directly connected to the hearing aid or implant through a DAI (Direct-Audio-Input) program, or inductively in the case of hearing aids (by using the telephone loop program – T). Currently, Bluetooth technology is most commonly used.

Hearing assistive devices include:

a) FM Systems – A personal device consisting of a transmitter and receiver, on the basis of radio waves (or, increasingly today, available technologies) – eliminating adverse environmental conditions, such as noise and reverberation, allows better hearing;

b) Devices for direct communication of the aid with a telephone or other tele-audio equipment (tele-transmitters);

c) Induction loops – individual or multi-recipient devices support hearing using the phenomenon of electromagnetic induction. They allow the user to hear sound equally well anywhere within the area bounded by the loop. They are mostly used in public places.

All the results of studies on wireless accessories published so far have focused on school-age users or adults (Wolfe, Morais, & Schafer, 2015, pp. 537–538; Wolfe, Duke, & Schafer, 2016; Razza et al., 2017, p. 74). The results indicated the benefits that patients achieved in terms of speech recognition in both quiet and noisy environments. Proving the benefits that wireless accessories offer in supporting the primary devices is important from the point of view of education and therapy that aim to develop speech in preschool- and early-elementary-school-aged children with hearing impairments.

The study aims to test whether differences in hearing and understanding speech before and after the use of hearing assistive devices can also be observed in preschool- and early-elementary-school-aged children.

Material and method

In the years 2017–2018, in schools and therapeutic centers for the rehabilitation and education of children with hearing impairments, a project was carried out to observe the benefits of the use of a wireless mini-microphone made by Cochlear (Fig.1) as an assistive hearing device for children with cochlear implants (CI)[1]. The project involved patients from four therapeutic centers: Mikołów (Non-Public Psychological and Educational Counseling Center TERAPIS), Krosno (Association of Parents and Friends of Children with Hearing Loss), Bydgoszcz (16th Greater Poland Uhlan Regiment School Complex No. 7), and Warsaw (Otton Lipkowski Residential Special Needs School for Hard-of-Hearing Children No. 15). The parents of all the children with cochlear implants who participated in the study gave written consent to their children's participation in the study.

The study was conducted in a group of n = 25 children aged 3.0 to 8.0 years (min = 3.0, max = 8.0, mean = 5.9, median = 7). The criteria for inclusion in the study were: a) all children had been users of an implant by Cochlear and a Nucleus 6 sound processor for at

[1] The study was funded by Cochlear. The participants received mini-microphones free of charge.

least one year; b) they had no previous experience with a wireless mini-microphone; c) the hearing map was stable – without the need to change the processor settings between appointments at the rehabilitation center throughout the duration of the experiment.

Figure 1. Wireless mini-microphone produced by Cochlear

The study used observation and survey methods. It consisted in observing the reactions of children with cochlear implants to speech sounds in various acoustic situations in two configurations: without using the mini-microphone and with the aid of this device. The results were recorded in an observational questionnaire. The tests were conducted in two age groups:

a) Group 1 – Preschool age (3 ≤ age < 6; mean = 4.0),
b) Group 2 – Early elementary school age (6 ≤ age < 8; mean = 7.4).

Observational questionnaires were filled in by the therapists and parents.

The test procedure consisted of several stages:

1. Developing class scenarios that would allow observations of the child's auditory reactions in a natural situation for the two age groups. Developing questionnaires for therapists and parents. Distributing class scenarios to therapists in individual centers.
2. Conducting the first class without a mini-microphone in each age group in individual centers according to the scenarios. The classes were conducted by two therapists: one repeated every exercise with children two times, the other recorded the reactions of

individual children in the questionnaire. One of the authors of the study also participated in the exercises as an observer.

3. After the first classes, the parents were asked to complete the parent questionnaire, and the children were given individually tailored wireless mini-microphones. The parents and therapists were trained in their use. The parents' attention was especially drawn to the need for their child to carry the mini-microphone in everyday situations in the home and preschool during the next five weeks. Each of the therapeutic centers also had its own mini-microphone paired with the children's devices.
4. After five weeks, the second class was conducted according to the same scenario with the wireless mini-microphone. The mini-microphone was worn by the teacher and was connected to all the processors of the children attending the class. Before starting the class, the connection between all the processors and the device was checked. The parents and therapists completed the questionnaires after the class was conducted according to the same procedure.

At least two speech therapists participated in each of the classes: one person conducted the classes and the other focused on observing the children's responses and completing the questionnaires. The speech therapists recorded their observations on each child's response in a particular situation and filled in the data in specially prepared questionnaires. The class scenarios included: group discussion when the child with a cochlear implant can/cannot see all of the other interlocutors, group discussion with a fan/TV turned on, spatial/directional hearing, and recognizing the voice of people the child knows.

The questionnaires that the parents and therapists filled in concerned the hearing of the children with cochlear implants and included the following issues:

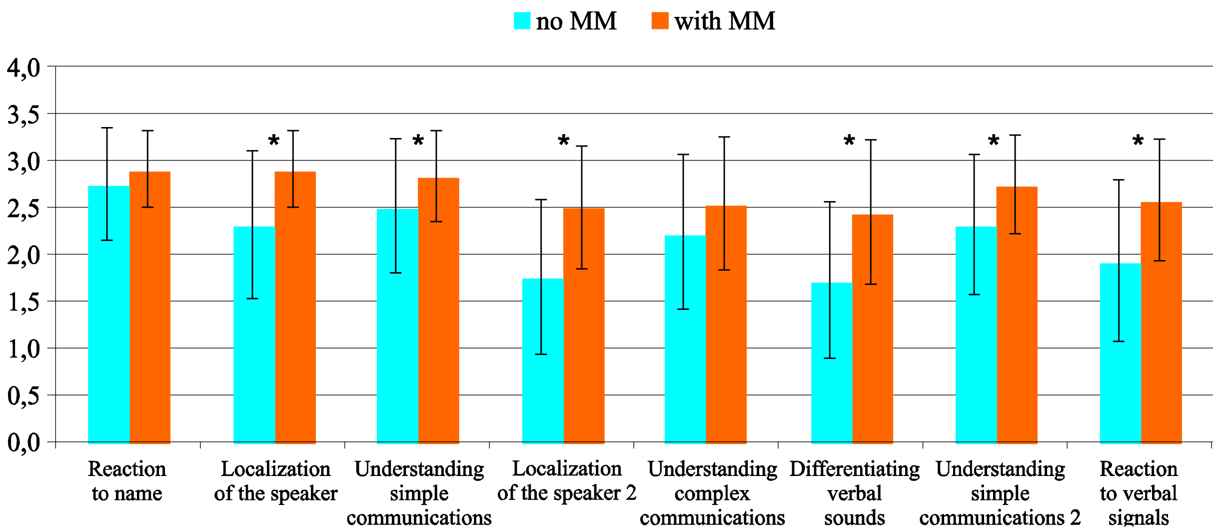
1. Reaction to sound – understood as interrupting the activity being performed, changing facial expressions, turning the head, pointing a finger to an ear or verbal response;
2. Localization – understood as a reaction to a verbal sound and turning in the direction of, or approaching, the person who made it;
3. Quality of hearing – understood as the identification of the speaker and the understanding of the communication.

For the analysis of the results of the observational questionnaires, each text value was assigned a numerical value: immediate reaction = 3, deferred reaction = 2, no reaction = 1. The results were analyzed with the Statistica software v. 13 (statistical analysis) and

Microsoft Excel (graphs). Statistical analysis was carried out with the Wilcoxon test, with a significance level of $\alpha = 0.05$.

Results

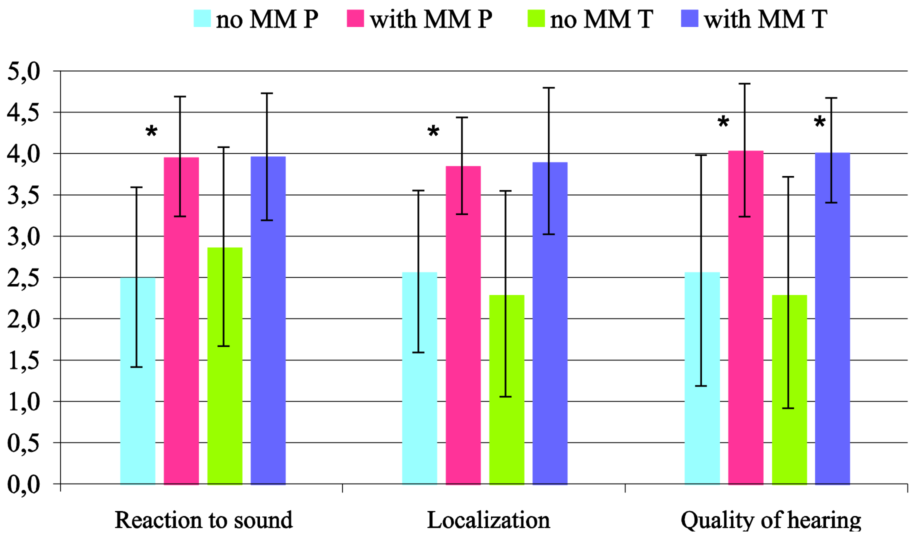
The results collected from the therapists' subjective assessment are shown in Graphs 1 and 2.



Graph 1. Results of the observation questionnaires completed in preschool classes in two configurations without age groups: without mini-microphone (‘no MM’) and with mini-microphone support (‘with MM’); mean value incl. standard deviation, $n = 25$, $^*p < 0.05$.

Statistically significant differences were shown for both the younger and older children in the area of speaker localization in easier ($p = 0.042523$) and more difficult acoustic conditions ($p = 0.038153$), where an average deferred reaction without mini-microphone support improved to an almost immediate reaction with the mini-microphone. The group of older children further demonstrated statistically significant differences in differentiating verbal sounds ($p = 0.011719$) and responses to verbal signals ($p = 0.011719$). These results coincide with the generalized, non-age-group outcomes, where there is an increasing trend in the area of response to name and in the understanding of complex communications but without statistically significant differences. To sum up, the general trend is that of the child's accelerated response to an acoustic signal with the mini-microphone hearing assistive device. The analysis of the results showed children's age was no statistically significant in the areas analyzed in the study (at the significance level $\alpha = 0.05$).

The questionnaire created for parents and therapists was devoted to assessing the child's perception of speech sounds in various acoustic situations. The responses given by these two groups did not differ statistically from each other.



Graph 2. Questionnaire results from parents (P) and therapists (T) without age groups; assessment of the child's response without a mini-microphone ('no MM') and with a mini-microphone ('with MM'); *$p < 0.05$ between groups without MM and with MM in the area of hearing quality; Lack of statistically significant differences between the P and T groups. Scale 0–5, where 0 – the child does not produce a reaction to a stimulus, 5 – the child responds perfectly to the verbal stimulus.

However, in the parents' assessment, differences in the child's response are statistically significant when the hearing assistive device is switched on ($p < 0.05$). For each sub-area (response to sound, sound localization, and quality of hearing) and for each age group, statistically significant differences between the results achieved with the mini-microphone, compared to without the mini-microphone, are noticeable. This indicates that the mini-microphone makes it easier for implant users to function, improving their responses to verbal, acoustic stimuli. Graph 2 clearly shows an improvement in performance and an upward trend indicating the benefits of using a wireless mini-microphone. The results obtained confirm the effectiveness of the wireless device and demonstrate the benefits from its use in the areas of response to sound, the quality of hearing, and sound localization.

The analysis of the results of therapist questionnaires, broken down by age group, did not demonstrate statistically significant differences for the different sub-areas – it should be pointed out that there were fewer questionnaires filled in by the therapists than those filled in by the parents. Statistical analysis of the results in terms of the children's age showed that the differences are statistically significant only when assessing sound localization without mini-microphones in the therapist questionnaires – older children coped better with sound localization without the assistive device.

Discussion

Assistive hearing technologies are frequently used by patients along with their primary hearing devices because they are designed to increase the comfort of hearing (Duke, Wolfe, & Schafer, 2016). They are also used by parents of very young children who are just starting to acquire a language system. This is to make it easier for small patients to focus their attention on speech sounds. Carol Flexer reports that children use an auxiliary device along with their primary device for up to 60–70% of the day and it is a "third ear" for them (Flexer & Cole, 2015, pp. 194–195). It is, however, worth stressing that in order for the use of this type of equipment to be tailored to children's needs, as the level of their auditory skills increases, we should make sure it is not overused and accustom children to normal acoustic situations. It is certainly worthwhile to implement such solutions in educational establishments where we will never achieve an acoustic background that would allow full contact with children with hearing impairments.

The results of the studies on the use of wireless accessories by implant recipients published so far have focused primarily on adult users or older schoolchildren (Beiter & Neil, 2015, p. 110). The manufacturer's clinical tests have proven the effectiveness of mini-microphones in severe acoustic conditions in the case of children younger than 7 (Mauger et al., 2014, p. 570; Razza et al., 2017, p. 74). Previous studies have shown benefits: improved recognition and understanding of speech in quiet and noisy environments. This is also confirmed by the results of our research.

The results of neuroimaging studies have shown the need to deliver good quality sound due to the formation of auditory perception processes in the cortical structures up to 6 years of age (Sharma, Dorman, & Kral, 2005, p. 141; Sharma, Nasha, & Dorman, 2009). There are opinions that 3-4-year-old children with hearing loss should not use hearing aids on a permanent basis due to the ongoing development process of localization and distance estimation skills (Flexer & Madell, 2008, pp. 193–194). It is worth remembering that a "mixed mode" can be used then, which in addition to amplifying speech sounds, gives the opportunity to hear ambient sounds. Demonstrating the benefits of wireless accessories for preschool- and early-elementary-school-aged children is extremely important for the rehabilitation and speech development of these children.

Summary

The results of the study conducted among children of up to 8 years of age with hearing loss using mini-microphones showed that as assessed by both their parents and therapists, the use of the devices brings the patients measurable benefits. Their response to verbal sounds and localization of these sounds significantly improved, which affects the communication of the children with cochlear implants with their peers and teachers. Improving the quality of hearing, in turn, has an impact on the understanding of communications directed toward the children with cochlear implants, thus facilitating their functioning in the group. This shows that it is necessary to use hearing assistive devices (mini-microphones) in the daily functioning of children with cochlear implants in a noisy environment (during group therapy, educational activities, and meetings with family or a group of friends).

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Bibliography

ASHA (1996). Central auditory processing: Current status of research and implications for clinical practice. *American Journal of Audiology*, *2*, 51–55.

Augustyńska, D., & Radosz, J. (2009). Hałas w szkołach – przegląd badań. [Noise in schools – Research review]. *Bezpieczeństwo Pracy – Nauka i Praktyka*, *9*, 16–19.

Beiter, A.L., & Nel, E. (2015). The history of Cochlear™ Nucleus® sound processor upgrades: 30 years and counting. *Journal of Otology*, *10*(3), 108–114.

Crandell, C.C., Smaldino, J., & Flexer, C. (2004). *Sound field amplification: Applications to acoustics and speech perception.* Boston: Delmar Cengage Learning.

Duke, M.M., Wolfe, J., & Schafer, E. (2016). Recognition of speech from the television with use of a wireless technology designed for Cochlear implants. *Journal of the American Academy of Audiology*, *27*(5), 388–394.

Domagała-Zyśk, E. (2013). Using technology to teach English as a foreign language to the deaf and hard-of-hearing. In E. Vilar Beltran, C. Abbott, & J. Jones (Eds.), *Inclusive language education and digital technology* (pp. 84–102). Bristol/London/Toronto: Multilingual Matters.

Flexer, C., & Madell, J.R. (2008). *Pediatric audiology.* NY: Thieme.

Flexer, C., & Cole, E.B. (2015). *Children with hearing loss: Developing listening and talking, birth to six (3rd ed.).* San Diego: Plural Publishing.

GUS – Główny Urząd Statystyczny [Main Statistical Office] (2018). Oświata i wychowanie w roku szkolnym 2017/2018 [Education in the school year 2017/2018]. Warszawa, https://stat.gov.pl/obszary-tematyczne/edukacja/edukacja/oswiata-i-wychowanie-w-roku-szkolnym-20172018.1,13.html.

Hart, B., & Risley, T.R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore: Paul H. Brookes Publishing.

https://medicusexpert.pl/product/mini-mikrofon-bezprzewodowy-cochlear/

Mauger, S.J., Warren, C.D., Knight, M.R., Goorevich, M., & Nel, E. (2014). Clinical evaluation of the Nucleus 6 cochlear implant system: Performance improvements with SmartSound iQ. *International Journal of Audiology*, *53*(8), 564–576.

Razza, S., Zaccone, M., Meli, A., & Cristofari, E. (2017). Evaluation of speech reception threshold in noise in young Cochlear™ Nucleus® system 6 implant recipients using two different digital remote microphone technologies and a speech enhancement sound processing algorithm. *International Journal of Pediatric Otorhinolaryngology*, *103*, 71–75.

Robinson, K. (1998). Implications of developmental plasticity for the language acquisition of deaf children with cochlear implants. *International Journal of Pediatric Otorhinolaryngology*, *46*(1–2), 71–80.

Sharma, A., Dorman, M.F., & Kral, A. (2005). The influence of a sensitivity period on central auditory development in children with unilateral and bilateral cochlear implants. *Hearing Research*, *203*(1–2), 134–143.

Sharma, A., Nash, A.A., & Dorman, M. (2009). Cortical development, plasticity and re-organization in children with cochlear implants. *Journal of Communication Disorders, 42*(4), 272–279.

Wereszka K. (2017). Uczeń z wadą słuchu w integracyjnym i włączającym systemie nauczania [A hearing-impaired student in an integrated and inclusive education system]. *Forum Pedagogiczne*, *2,* 91–104. doi: 10.21697/fp.2017.2.07.

Wilczyńska, I., Paciej, J., & Hudzik, G. (2012). Ocena narażenia na hałas uczniów i nauczycieli klas I–III szkół podstawowych na przykładzie województwa śląskiego. Wojewódzka Stacja Sanitarno-Epidemiologiczna w Katowicach. [Assessment of exposure to noise in Grade 1–3 students and teachers in primary schools in Silesian Voivodeship.

Regional Sanitary and Epidemiological Station in Katowice]. *Problemy Higieny i Epidemiologii*, *93*(4), 888–893.
Wolfe, J., Duke, M.M., & Schafer, E. (2016). *Evaluation of wireless, digital, audio-streaming accessories designed for the Cochlear™ Nucleus® 6 Sound Processor*. FUN 2249 ISS1, Cochlear.
Wolfe, J., Morais, M., & Schafer, E. (2015). Improving hearing performance for cochlear implant recipients with use of a digital, wireless, remote-microphone, audio-streaming accessory. *Journal of American Academy of Audiology*, *26*(6), 532–539.
Zaborniak-Sobczak, M., Bieńkowska, K.I., Drozd, M., & Senderski A. (2018). Wsparcie edukacyjne uczniów z centralnymi zaburzeniami przetwarzania słuchowego. [Educational support for students with central auditory processing disorder]. *Niepełnosprawność. Dyskursy Pedagogiki Specjalnej*, *29*, 115–131.
Zaborniak-Sobczak, M., Bieńkowska, K.I., & Senderski, A. (2016). Centralne zaburzenia przetwarzania słuchowego: od teorii do praktyki edukacyjnej. Wybrane problemy [Central auditory processing disorder: From theory to educational practice. Selected issues]. *Niepełnosprawność. Dyskursy Pedagogiki Specjalnej*, *23*, 116–132.