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The Significance of the Physical and Motor Potential for Speech Development in Children with Cochlear Implant (CI) – Preliminary Study

SUMMARY

The analysis of neurophysiological development processes of implanted children with profound hearing loss does indicate the links between the level of language skills development and motor functions within the scope of both fine and gross motor skills. The purpose of the research, that was carried out within the two week rehabilitation period on a group of 17 children with profound hearing loss, now cochlear implant users, was to verify whether the launch of Early Intervention programme (in the form of global movements, focused on the vestibular system) will be effective in improving motor skills and strongly correlate with the level of speech development. The results did confirm the hypothesis of the effectiveness of impact-oriented motor exercises on the vestibular system that aimed to improve the sense of direction. Moreover, it showed the significant presence of relevant neurophysiological bonds in the scope of development of balance of language skills. The presented results do confirm the few global reports on this subject. Likewise, in order to search for best possible therapies for children – cochlear implant users – they point the urge to conduct a continuous survey in the field of coordination motor abilities (CMA) as well as in terms of development of linguistic competencies.

Key words: hearing impairment, vestibular system, language level skills, cochlear implant, therapy

INTRODUCTION

The process of multistage treatment of profound hearing loss by using cochlear implant is an interdisciplinary problem. It requires to interconnect the knowledge from the field of medicine practice, technology, logopaedics, linguistics, deaf education, psychology, sociology, and rehabilitation (Szkiełkowska et al. 2008; Szyfter et al. 2011). So far, significant benefits of using cochlear implants for the process of hearing development and perception in children with severe and profound hearing loss have been well documented (Nicholas, Geers 2006; Easwar et al. 2010; Geers et al. 2013). Acquiring linguistic competences (language skills), communication abilities and cultural consciousness, which are essential to use language in effective and situation-appropriate way, is conditioned by the capableness of reception and implementation skills, biologically determined and connected to the general psychomotor development of the child (Grabias 2003).

Speech production is indisputably a movement act, linked to the motility of oral cavity and respiratory functions (Eskander et al. 2014; Żebrowska, Zwierzchowska 2006; Żebrowska et al. 2016). Therefore, neurophysiological analysis of developmental processes and their mutual dependencies in children – both hearing and with hearing defects – is not insignificant. Researchers such as Horn et al. (2006) or Willems, Hagoort (2007) indicate essential connections between acquired language capabilities and motor functions within the scope of both fine and gross motor skills.

Motor Development is situated in the center of biological human development, and reflects its different aspects, like perception as well as speech planning and activation. It is also the act of taking control over muscles, displayed by balance ability (postural control), which is preliminary condition to perform complex motor activities. Balance is the ability belonging to coordination motor abilities (CMA), which provides the base for effective and optimally performed motor activities. Both static and dynamic body balance is very important to carry out complex motor activities (Raczek et al. 1998). The research point out the significant connection between hearing loss etiology and physical development, since the etiopathogenesis of hearing dysfunction is linked to child's birth potential and forms the basis for its further development (Butterfield 1989; 1991; Zwierzchowska et al. 2008; Zwierzchowska 2009). Hence, it is hard to expect that children with hearing impairment (having sometimes also conjunctive neurological and vestibular system disorders) will perform planned movements correctly and in accordance with the physiological pattern. In these circumstances, understanding the neurophysiological basis of body control as well as the assessment of the motor coordination of the child with hearing impairment is the basis for proper rehabilitation (Zwierzchowska 2013).

Simultaneously, the available data concerning the influence of cochlear implants on psychomotor functions are not straightforward (Todt et al. 2008). The authors point to the diversification of factors contributing to the individual successes of the child after cochlear implantation (Pyman et al. 2000; Bieńkowska 2017). Many studies indicate positive effects of motor rehabilitation in children with hearing defects for the development of auditory skills, speech reception and its production (Bouccara et al. 2005; Ganek et al. 2012; Yoshinaga-Itano et al. 2010).

The considerations, mentioned above, have become the basis for the creation of a theoretical model of connections between selected aspects of the development of the child with hearing impairment. It may be important particularly in planning the therapy of children with hearing disorder most often performed by surdologopedists and surdoteachers (Fig. 1).

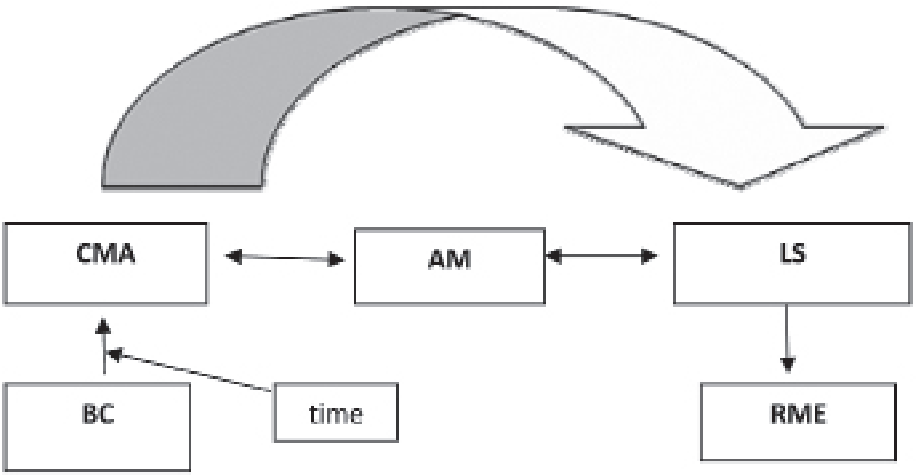

Fig. 1. Theoretical model of connections between selected aspects of child development with hearing impairment

CMA – coordination motor abilities; AM – articulation motility; LS – language skills; BC – birth condition; RME – respiratory muscles efficiency

Previous research results, as well as the theoretical model of links between the selected aspects of child development with hearing defects, allowed to formulate the following research questions:

1. Is there a relationship between the level of assessed CMA and the language skills of children with deep hearing loss after cochlear implantation?
2. How does the newborn condition, measured by the Apgar Score, affect the level of assessed coordination skills?
3. What is the relationship between the functional efficiency of respiratory muscles and the level of language skills?

MATERIAL AND METHOD

The method of direct and participant observation was applied, subjecting 17 children with deep hearing loss with a cochlear implant (single and double-sided), aged from 4.2 to 10.1 (= 6.7 ± 1.7, median = 6.1). In July 2016, they participated, altogether with their parents, in a rehabilitation camp, organized by the Association of Parents and Children's Friends with Disability of Hearing in Krosno. The study and its assumptions are described in a separate article (Zwierzchowska, Bieńkowska 2016). All of the examined children had a hearing disability detected in screening examinations and were cured from the first year of life (prosthesis – hearing aids, cochlear implant) and given proper treatment (like hearing and speech therapy performed 2 times a week in a rehabilitation center, verbal and auditory education at home).

Physical development was assessed by performing basic body measurements (height (BH), body mass (BM), hip circumference (H) and waist (WC) and chest at rest (CR), maximum inspiration and maximum exhale, which allowed to estimate the efficiency of respiratory muscles (RME) (Table 1)). The following indicators were calculated: WHtR (waist-to-body ratio), BMI (body mass), which helped to assess the physical condition of the subjects with regard to centile graph (CZD 2012). To identify the occurrence of abdominal obesity, centile graphs were used for waist circumference and WHtR index. According to reference values for Polish children (Nawarycz, Ostrowska-Nawarycz 2007), it was assumed that there is an increased risk of abdominal obesity (which may affect balance maintenance), if waist circumference was above 90^{th} percentile for age and gender, or WHtR was equal to or greater than 0.5.

Furthermore, data on the birth condition (BC) were collected (according to the Apgar score). The scale aims to estimate the general health of the newborn and to detect any abnormalities that require immediate reaction. The assessment takes place at 1, 3, 5, 8 and 10 minutes after child's birth to check the fluctuation of its health. The Apgar score examines five basic life parameters: breath, heart function, muscle tension, reactions and skin color. The rating can be given from zero to two points, where zero means unsatisfying result, 1 is medium, and 2 is good. The final grade is obtained by checking individual parameters and summing up their values. A newborn can receive between 0 and 10 points in every stage of the examination. The obtained result is interpreted as follows: 10 points indicate a very good condition of the newborn; 9–8 points indicate a good condition, such aneonate is usually "only" tired of childbirth and regains optimal notes in reduced parameters in a short time; 4–7 points indicate the average condition of the newborn (the child might be bruised, irregularly breathe, or with lowered muscle tone – depending on the parameters); 3–0 points receives a newborn baby requiring immediate medical intervention, breathing support and cardiac work.

The tests, performed on selected coordination motor skills (CMS), were conducted and evaluated in accordance with the instructions (Raczek et al. 1998): RS – reaction speed (Ditrich stick test), SO – spatial orientation (test: march to the target), MA – motor adaptation (test: forward-backward jumps), static balance – SB (climbing on toes) and dynamic balance – DB (test: tip-top march).

In order to rate language skills (LS), due to the lack of a standardized tool for examining children with hearing defects in Poland, the authors used a structured questionnaire "60 steps card" (60SC), which is part of the therapy program (Bieńkowska 2012) and allows to obtain point results and make them comparable. It is a tool created for the needs of diagnosis during hearing and speech therapy of children with hearing impairment, constructed on the basis of identifiable (described in the literature) stages of speech development. Each step is matched by the language skills described. "60 steps card" consists of 60 fields, which correspond to 60 steps, or 60 skills that can be achieved by the child (in the zero-one system), on four language levels. Each acquired skill is one point. A child can reach a maximum of 60 points. The first level evaluates 13 pre-lingual skills related to hearing and sounds attention (indicators such as the detection of ambient sounds, speech and the reaction to them – or its lack – are rated). The second level evaluates the 12 skills achieved by the child at the initial language level by developing preverbal communication skills at the suprasegmental level of the language. The third level, called the level of verbal communication, defines 21 skills within the development of passive and active speech. It ranges from the stage of understanding the first words to the act of building compound sentences. On the last, fourth level, there are 14 skills (no. 47 to 60) of using language as a tool for developing higher intellectual skills on the level of native speaker.

The assessment of whether the child has achieved the skills on the next level (or not) is facilitated by auxiliary questions (Bieńkowska 2012). According to the adopted standard, the results of the interview are orderly marked on the Evaluation Sheet (60SC) by the therapist conducting the child. Points sum up, and the higher score is reached, the higher level of language development the child represents. For the needs of the present study, the children were separately examined by the authors of the article, and their results were compared with the assessment issued by the therapist conducting the therapy in the rehabilitation center.

The research was carried out during a speech therapy camp for hearing-impaired children during which there was a stimulation of auditory and speech functions (see Bieńkowska, Zaborniak-Sobczak 2015). All of the participants and their guardians expressed their willingness to participate in the project in which main goal was to improve hearing and speech. They expressed their acceptance for the assessment of selected motor skills during 14-day rehabilitation stay. The research procedure for children with hearing loss has been approved by the University Bioethics Committee for Scientific Research at the University of Physical Education in Katowice (Resolution No. 1/2012 of 13/12/2012 and the Appendix no. 11/03/2013).

STATISTICAL ANALYSIS

The results were processed in the MS Excel program and statistically analyzed in the Statistica 10.0 program, calculating the mean value, median, standard deviation, upper and lower quartiles. The comparative analysis was performed with the parametric test and the relationship strength was verified using the Pearson test at the significance level of $p<0.05$ according to the formula: r (x, y) = cov (x, y) σx * σy: cov (x, y) = E (x * y) - (E (x) E * (y)); where: r (x, y) – Pearson correlation coefficient between variables x and y; cov (x, y) – covariance between variables x and σ is the standard deviation of the population; and E is the expected value. The correlation interpretation was applied according to the J. Guilford classification, where r = 0 – no correlation, 0.0 <| r | ≤ 0.1 – weak correlation; 0.1 < r | ≤ 0.3 – weak correlation; 0.3 <| r | ≤ 0.5 – average correlation; 0.5 < | r | ≤ 0.7 – high correlation; 0.7 < | r | ≤ 0.9 – very high correlation; 0.9 < | r | < 1.0 – almost full correlation; | r | = 1 – full correlation.

RESULTS

Fifteen respondents were included in the analysis due to the fact that two children were unwilling to cooperate and finally backtracked from the examination. The collected data provided information on the birth condition (BC) of the examined children, expressed in the value of points obtained according to the Apgar score, where the average value was (9.3 ± 0.8) min–max 8–10; median = 9. In addition, information about the age of hearing loss detection (under 6 months of age) was obtained. It was also performed an audiometry test in a free auditory field, where the mean value x = 30.3 ± 6.5; min–max (20–45dB).

The analysis of individual results of the physical development status in the examined children showed obesity risk in 28.5% of respondents in relation to the percentile graph (CZD 2012). On the other hand, the median and WHtR ratio median, in both boys and girls, were below 0.5, which indicates that the majority of children were not at risk of abdominal obesity.

Table 1. Characteristics of the physical condition of the patients

Feature	BH [cm]	BM [kg]	BMI kg/m]	WC [cm]	WHtR	CMA [cm]	RME [cm]
$\bar{x}$ ± SD	119.9 ± 10.9	24.0 ± 4.8	16.6 ± 1.8	57.9 ± 5.3	0.5 ± 0.05	60.3 ± 5.1	3.3 ± 1.3
Min–max	104–142	18–34	12.6–19.1	59–79	0.4–0.6	55–75	2–6
Median	118	23	16.8	56	0.5	60	3

BH – body height; BM – body mass; BMI – body mass index; WC – waist circumference; WHtR – waist-to-height ratio; CMS – coordination motor abilities; CR – chest at rest; RME – respiratory muscles efficiency

The level of coordination motor skills was measured, the scores of which are presented in Table 2.

Table 2. The level of coordination motor abilities

	Coordination motor abilities				
Parameter [unit]	SB [sec]	DB [number]	SO [number]	RS [cm]	MA [cm]
$\bar{x}$ ± SD	4.1 ± 2.9	4.8 ± 0.8	76.6 ± 44.1	21.3 ± 8.1	33.7 ± 17.0
Min–max	1–11	3.9–6.3	12–150	3–33	5–60
Median	3.0	4.5	73.5	21	40

SB – static balance; DB – dynamic balance; SO – spatial orientation; RS – reaction speed; MA – motor adaptation

The score of the card evaluating the level of language skills development (60SC) ranges from min–max (28–54), where the median equals 44 and the mean value was 42.9 ± 6.2. The analysis of relationship calculated by Pearson test showed that language skills significantly correlated with one of the functional features, that is the efficiency of the respiratory muscles at a high level of R = 0.6, indicating that the higher efficiency of respiratory muscles, the better level of language skills is developed.

There was also observed the inversely proportional correlation, statistically significant, between the results of CMS tests in such abilities as fast response and the child’s age at the high level (R = -0.6), which indicates the older the child, the shorter the response time. Similarly, a high correlation occurred in the case of language skills (R = -0.6) and between the value of the birth condition rated with the Apgar score (R = -0.3), but the correlation was weak in strength. Dynamic balance was significantly correlated with the age of the respondents (R = 0.5) as well as with the result of the LS test, but in this case, the relationship strength was very high (R = 0.8) (Table 3).

Table 3. Coordination motor abilities in relation to age, Apgar score and level of language skills

Coordination motor abilities					
Test (R)	SB	DB	SO	RS	MA
Age	0.6	0.5*	0.02	-0.6*	0.5*
BC – Apgar score	0.1	-0.1	0.6*	-0.3*	0.01
LS – 60SC	0.2	-0.8*	0.1	-0.6*	0.3

*p<0.05; SB – static balance; DB – dynamic balance; SO – spatial orientation; RS – reaction speed; MA – motor adaptation

The research has also shown a high correlation between spatial orientation and birth condition measured with the Apgar score (R = 0.6), while motor adaptation moderately correlated with age R = 0.5. Correlations at the level of $p < 0.05$ were assumed as statistically significant.

DISCUSSION

CMA, including the speed of reaction, spatial orientation and balance, are the abilities whose development may be determined by deafness, because the perception of the environment is shaped in modified sense conditions. Simultaneously occur conjugated neurological and vestibular disorders (Zwierzchowska et al. 2004; 2008). Myklebust (1964), and Remlein-Modzelewska (1998) believe that the main role in shaping the visual spatial placement is played by the so-called visual locational reflexes, which develop on the principle of combining retinal stimuli with the motor system, which seems to be a kind of compensation. Internal compensation, generated as a deaf-out effect, may result in better development of control functions, location and spatial orientation, causing effective and optimal use of it for the benefit of motor activities (Kral, Sharma 2012; Zwierzchowska et al. 2004). It seems that we are dealing with such a compensation while analyzing the results of our own research. Savelsbergh et al. (1991) came to a similar conclusion, examining deaf children, early implanted, indicating that sound stimulation manages and intensifies motor behavior in the sphere of visual orientation. These observations were confirmed by Schlumberger et al. (2004), who pointed to the essence of sound reception and better development of children early implanted in neuromuscular integration, motor control and spatial orientation. Confirmation of those thesis was accomplished by Zwierzchowska (2013), by evaluating morpho-functional dependencies in semi-longitudinal studies of children and adolescents with profound hearing loss, demonstrating the relationship between lung capacity, ability for both aerobic and anaerobic exercise and spatial orientation, and motor adaptation (correlations were high and very high). Our own research corresponds to these results, although the study group is significantly younger and, what is even more important, early implanted (1–3 years).

It is difficult to see other logical premises explaining the relationship between coordination abilities and respiratory muscle efficiency, the assessment of birth condition measured with the Apgar score and the child's age, while the latter parameter directly translates into the time of stimulation (therapy). The importance of internal compensatory processes in the period of biological development, externally strengthened by targeted stimulation in the therapeutic and educational process, should be also pointed out. These associations seem to be particularly important in the group of children with hearing loss detected in screening tests, who were earlier established and subjected to the process of early therapeutic intervention.

It should be noted that the time factor is particularly important, especially in the period of ontogenetic expansion, because of the characteristic feature of this period is progressiveness (Jopkiewicz, Suliga 2000). Hence, the directly proportional high and moderate dependence between age and dynamic balance, motor adaptation and reaction rate, demonstrated in our own studies, stands as confirmation for the physiological pattern of human development (the older the child gets, the higher the level of coordination capacity (dynamic balance, motor adaptation) and shorter response time is ($R = -0.6$)). The birth condition is the basis for development, while the time factor (the age of the child) together with environmental modifiers (not measured in the above study) is not without significance for the level of development of the CMA. The following research confirms the strong relationship between the level of high Apgar score and spatial orientation. The lack of similar analyzes for groups with other disabilities is a limitation for a deeper interpretation of these research results.

On the other hand, the results of research on coordination abilities development in non-disabled persons (Raczek 1992; Starosta 2001) correspond with the results of own research, confirming the preserved physiological development patterns of coordination motor skills. CMA is defined as human predispositions, which are closely related to its potential, and the time of their development is shortened with the maturation of CNS and the specialization and integration of senses (Szopa et al. 1996). One of the coordination skills, which is the first to achieve its developmental apogee, is the ability of balance (around the age of 8) and it constitutes the basis for further integrated processes, related to the neuromuscular control of our body. Raczek (1992, 75) argued that the ability of balance is a subject of development and can be successfully compensated by external stimulation (proper selection of exercises, environment). There are a few articles that report the possible damage of the balance organ as a result of inserting the cochlear electrode during implant surgery (Jacot et al. 2003; Bouccara et al. 2005; Enticott et al. 2006; Todt et al. 2008; Thierry et al. 2015). This thesis, however, may be a result of contradictory research reports, sometimes even developed by the same authors (Huygen et al. 1995). The problem of vestibular organs excitability, depending on the reported dizziness and imbalance of persons qualified for cochlear implant, is multidimensional, because it indicates numerous factors (like age, etiology of hearing loss, type of surgical technique, difficulties in collecting the interview) (Niemczyk et al. 2009). In the case of the studied group, this thesis cannot be confirmed, and the results of the following studies show a statistically significant, very high dependence ($R = -0.8$) of this ability and age. Undoubtedly, this result should be treated as an initial observation (so there is no standardization of the used tool) and it requires further research and confirmations, with a particular emphasis on correlations between large and small motility and articulation motor. Nevertheless, the obtained results seem to be particularly important for the therapeutic measures taken by speech therapists in children after cochlear implantation. In the previous empirical observations, attention was paid to the importance of movement in speech therapy for children with hearing impairment (e.g. during rehabilitation camps – Bieńkowska, Zaborniak-Sobczak 2015). It seems appropriate to apply a detailed differential diagnosis of the vestibular system in planning therapeutic treatment, with the use of interdisciplinary knowledge, unconventional rehabilitation procedures, considering the significance of physical exercises in speech therapy. Knowledge development in the field of clinical neurology, brain neuroplasticity and a significant effective role of the motor apparatus and sensory integration (Sharma et al. 2009; Flexer 2010; Gordon et al. 2013) is the basis for searching for new solutions in the scope of hearing improvement and speech rehabilitation after cochlear implant surgery. Hence, the identification of factors that may determine the individual development successes of the child after cochlear implantation is a field worth exploring. On the one hand, we deal with surgical intervention in the sensitive area of the auditory organ, and on the other hand, we should notice the value of acquiring the sound perceived as a factor not only allowing to develop phonic speech, but also stimulating motor behavior, which modifies the current biological condition of a deaf person. The justification for such a thesis is the result of own presented research, showing the relationship between the development of language skills and the efficiency of respiratory muscles, which corresponds with other studies (Żebrowska et al. 2016).

CONCLUSIONS

1. Neurophysiological relationships have been demonstrated in terms of coordination motor abilities level (dynamic balance and responsiveness), skills and language.

2. Birth condition and age are significant factors for the development of motor coordination abilities, which indirectly affects the level of language skills. The theoretical model of connections between selected aspects of child's development and hearing defects, created for the needs of the study, was confirmed.

3. Carrying out continuous research, both in the field of CMA and speech aspect, seems essential for effective, optimal methods of therapy for people after cochlear implantation.

IMPLICATIONS FOR SPEECH THERAPY PRACTICE

1. It is appropriate in the process of designing and implementing tasks in the field of improving language skills, to introduce global movement tasks with a complex structure, that can significantly support the acquisition of language skills. In addition, breathing exercises, involving both fine and gross motor skills, are also significant. Compulsory part of the therapy should, therefore, become logorhythmic and/or psychomotoric classes.

2. In the program of logopedic (surdologopedic) studies, it is advisable to broaden the knowledge block associated with the development of coordination motor abilities, physiology and pathology of the functioning of vestibular system with particular emphasis on the balance system.

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