WHITEPAPER
2021

Paediatric BrainHearing™

ABSTRACT

Children and teens with hearing loss, like their peers with typical hearing, wish to learn, have friends, understand who they are, and feel they belong. Crucial to their development is having full access to communication and their world of sound.

The Oticon BrainHearing philosophy aims to offer infants, children and teens with hearing aids that provide the brain with the very best sound information possible. Through proven BrainHearing technology, Oticon hearing aids provide them full access to the complete sound scene to support cognitive development, speech and language development, and the development of social relationships and inclusion.

Oticon has a history of providing BrainHearing technology for infants, children, and teens. Based on independent research studies by paediatric audiology researchers around the world, we have been able to show that Oticon hearing aids provide better access to speech information, improvements in speech understanding in noisy environments, and reduced listening effort.

EDITORS OF ISSUE

David Gordey
Director,
Pediatric Audiology &
Research
Oticon A/S

Elaine Hoi Ning Ng
Principal Researcher
Centre for the Applied
Audiology Research
Oticon A/S

oticon
life-changing **technology**

Introduction

Children grow up in a rich world of sound, and access to this sound is very important. Our world of sound includes directed speech, other people talking, and sounds in the environment. For children, this has an important function; teaching them how to interact with the world and to relate to the world around them. Research has shown that our auditory system has very important connections with our brain. For children, the developing brain is highly plastic and during its critical period, environment input and sensory experience are crucial. Carol Flexer described these aspects of the hearing process as "the ears being merely a doorway, and access point to our brain." Oticon's BrainHearing™ philosophy has been a key component of our research and development over the past 10 years. BrainHearing ensures that our hearing technology provides children and teens full access to spoken language and sound in all environments to support their cognitive development, speech and language development, social relationships, and inclusion.

Brain development in children

The human brain starts developing before birth, rapidly grows in early childhood, and continues into adolescence. A child's early experiences are crucial to how the brain network is wired and established (Figure 1). In the early stages, brain cells and neurons begin to grow. The connections between the brain cells and neurons, which are called synapses, are established. These development processes continue and are found to peak at early childhood. There is a massive production of synapses while the basic structure of the brain is being established.

After the huge production of synapses, the brain goes through a synapse reduction phase called pruning. It is here that neurons and synapses not needed by the brain are removed. The pruning phase selectively eliminates synapses based on their "activity history." For example, early sensory experience from the environment activates the neural connections in the cortical areas involving visual or auditory perception. As these connections are frequently used, they are more likely to survive in the pruning phase. Connections that are unused, or not activated by the environment, are eliminated. In this pruning phase, brain development is predominately driven by environment input. Shaped by early experience, the brain structure becomes more refined and neural connections become more precise. The pruning process allows flexibility, helping the developing brain to adapt to the specific environment. For cortical areas that are important for basic sensory functions such as visual and auditory perception, pruning takes place between four and six years of age (Conel, 1939). For higher cognitive functions, such as emotion regulation, pruning continues through adolescence (Huttenlocher & Dabholkar, 1997). Brain development is affected by early experience. Having full access to the sound environment in early childhood will optimally activate the connections essential for auditory development in a hearing brain (see Tierney & Nelson, 2009 for a review).

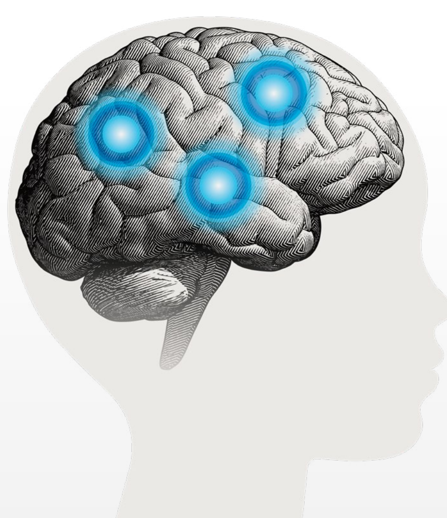


Figure 1. Brain development in early childhood is remarkably rapid. Sensory experience in the early years strongly influences the wiring of the brain network.

Critical periods and brain plasticity

The developing brain is highly plastic and a critical period refers to the period of rapid development when the brain plasticity is maximal. During this period, environment input and sensory experience are crucial for the optimal development of the brain and its network. The critical period (0-3 years of age) is the most favourable period to learn certain new skills and abilities, such as language and music. Basic functions such as sensation and perception are well developed in the early years of life; other higher-order functions and systems such as memory, decision making, and emotion continue to develop into adolescence and early adulthood. Figure 2 illustrates the critical periods of brain development for different functions and abilities (see Cisneros-Franco et al., 2020; Hensch & Bilimoria, 2012).

If a sensory experience is abnormal or absent during this time, the brain network will be wired in a different way, and preferentially represent the nondeprived sensory information. This effect is usually irreversible after the closure of the critical period and makes it difficult to learn certain skills later in life. For example, a reoccurring conductive hearing loss in early childhood may impair access to particular speech sounds and the ability to detect binaural cues. This may produce long-lasting impacts in auditory perceptual acuity (Stephenson et al., 1995). These impacts ultimately may affect the rate and quality with which a child acquires language abilities (Moore et al., 1991). Research has also shown that children who are born with bilateral profound hearing loss are likely to benefit more from cochlear implants if they receive the treatment before two years of age than those who are treated later in life (Kral & Eggermont, 2007). This highlights the importance of early intervention during this period of brain plasticity.

The development and maturation of the brain is shaped by both genetic and environmental factors. Brain plasticity is maximal during the critical period, and then decreases over the lifespan. Relative to the young developing brains, adult brains are less plastic and less favourable to the acquisition of new abilities. The foundations of sensory and perceptual systems are formed and are strongly influenced by experiences in the early years, and they are critical to language, social behaviour, and emotion development in later years. This illustrates the remarkably rapid brain development in early childhood and the brain's lifelong capacity for growth and change.

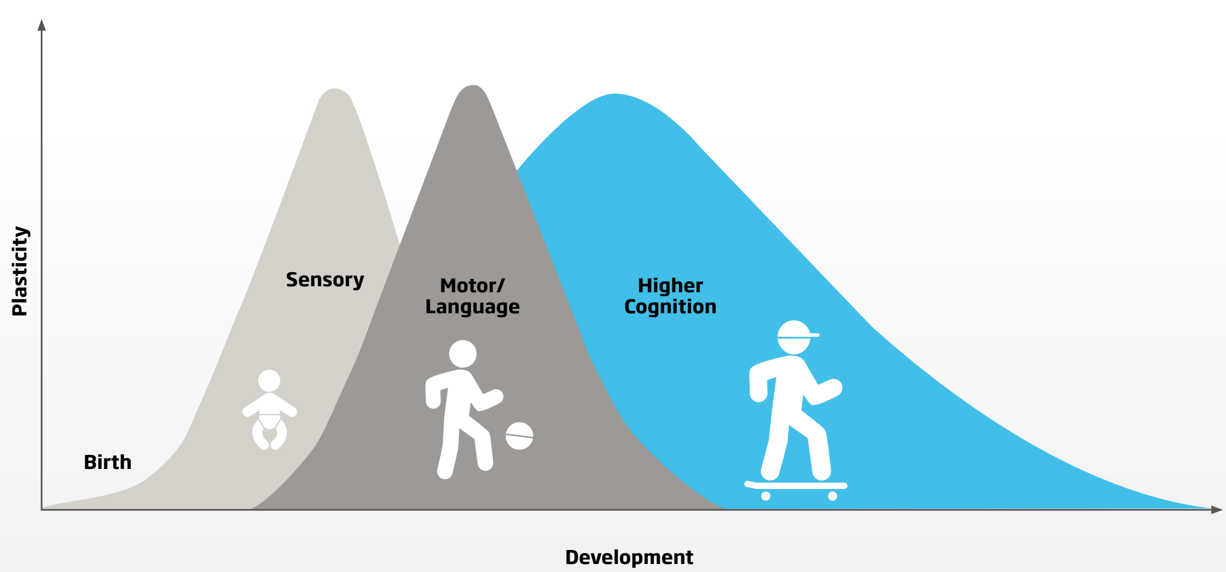


Figure 2. Critical periods for the development of sensory systems (vision and hearing), language, and higher cognitive function, as well as many other brain functions.

Brain development and children with hearing loss

Brain development is a hierarchical processes, for wiring the brain with higher level processes building on a foundation of lower-level processes. For example, language development depends critically on sensory and perceptual development (e.g., discrimination of speech sounds). The types of auditory input infants and children are exposed to help shape their brains and behaviour. For children with hearing loss, the auditory input to the developing brain may be suboptimal or distorted because of the deficits in the auditory system. Since the sensory input from the environment and experience shapes the maturation and development of the brain, hearing loss can have the following impact on the brain development in children with hearing loss:

1. Cortical maturation and development of sensory and perceptual systems

Insufficient, abnormal or absent auditory input in early experiences can negatively impact the establishment of neural connections and the development of auditory detection and perception. A typically developing brain learns the different physical features of auditory input and constructs representations of auditory objects. These features include frequency and intensity, binaural time and intensity differences, frequency modulation, and amplitude modulation. In addition, basic sensory and perceptual abilities along with spatial processing and binaural hearing are developing. The brain is able to discriminate the speech sounds of virtually all languages, but with experience it will be optimally tuned to the native language (see Kuhl, 2004, for discussion). Having a hearing loss can affect the young brain's ability to detect and discriminate these speech sounds. With the development of the auditory perceptual system being compromised, an impact on speech-language development can occur.

2. Auditory learning and speech and language acquisition

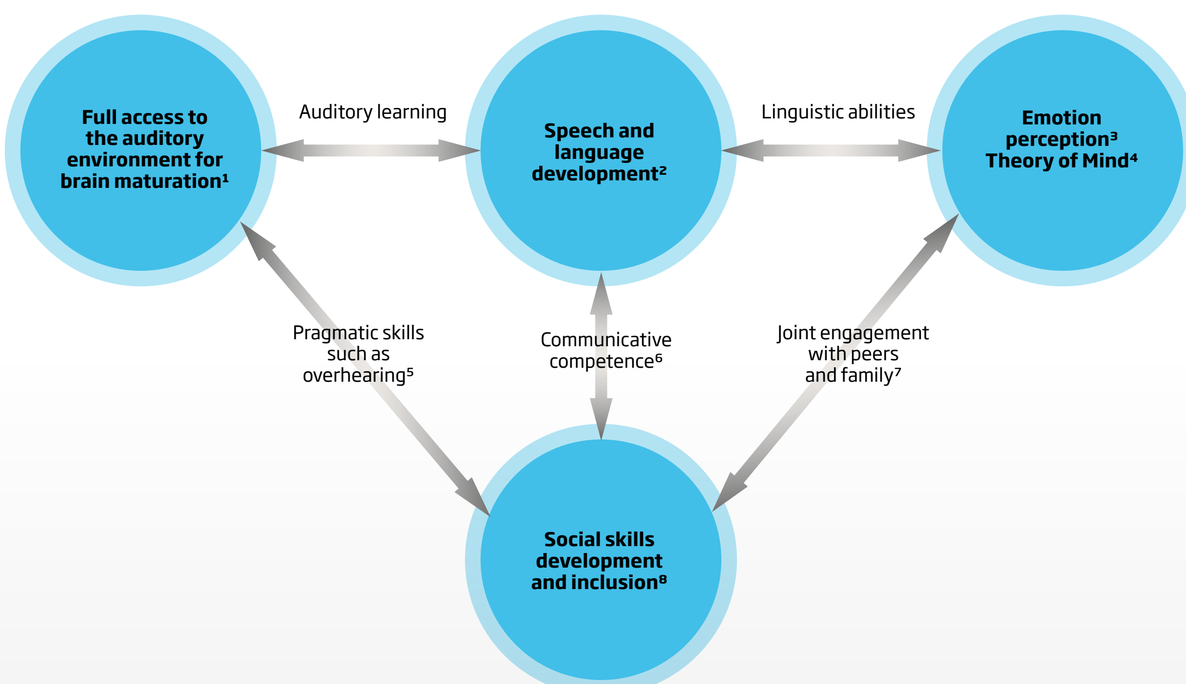
Within the first year of life, infants learn to discriminate among sounds that are specific to the language they are exposed to in their environment. Before six months old, infants can discriminate sounds of almost any language. Between six and 12 months, the brain begins to specialize in discriminating sounds of the native language and loses the ability to discriminate sounds in non-native languages (Kuhl et al, 2003). This narrowing of perceptual sensitivity is important because it is related to better discrimination of native language sounds which predicts better language skills later in life (Kuhl, 2004). Evidence from a longitudinal study showed that on average, preschoolers (aged two to six years) with mild to severe hearing loss did not reach the same language outcomes as a group of age and socioeconomic-matched normal hearing peers (Tomblin et al., 2015). In addition, language performance of the preschoolers who had more severe hearing loss was found to be poorer than those who had milder degrees of hearing loss. The study also showed that better audibility with hearing aids was associated with faster rates of language growth. Preschoolers with early fitted hearing aids had better early language achievement than those who were fitted later. These results support that hearing loss in early childhood affects speech language development and that poor sensory input due to hearing loss can be remediated with the use of hearing aids.

3. Emotion perception and abilities

Voice emotion recognition is important for the development of social competence and linguistic knowledge. It enables children to maximize the information obtained from spoken language and interact appropriately in different social settings. The ability to perceive complex pitch variations in speech (low frequency range in particular) is essential in identifying emotional prosody. Previous studies of voice emotion recognition in children with hearing loss who use hearing technology suggest deficits in voice emotion recognition (e.g. Chatterjee et al. 2015). Furthermore, childhood hearing loss has been linked to delayed development of "theory of mind", or empathy/emotion understanding and recognition (e.g., Peterson, 2004). In addition, examples of pre-school aged children with hearing loss also have shown deficits in theory of mind (Walker et al., 2016), and interindividual emotion recognition have been noted and considered a factor for reduced empathy (Netten et al., 2017). The inability to perceive emotions compromises one's ability to communicate effectively. It may also have broader quality of life effects, such as poorer performance at school and in the workplace (see Picou et al., 2018 for review).

4. Social skills development: the importance of language, communicative and pragmatic competences

Language skill development precedes the emergence of social skills and having social competence is important for emotional and behavioural development. Hoffman et al (2015) investigated the hypothesis that children with hearing loss who have delayed speech language development would also show delay in their social skills. The study found that children with hearing loss (2.5 – 5.3 years) had poorer language and social skills (social competence and behaviour in classroom as well as social-emotional abilities) than their normal hearing peers. However, those children who received amplification at an earlier age showed better social skills than those who received amplification later. The study also confirmed that language delays have cascading negative effects on the development of social skills. This was also supported by Constantinescu-Sharpe et al (2017), who showed children with hearing loss (four to five years) and age-appropriate spoken language had comparable social outcomes to those of children with typical hearing. The development of pragmatic skills is also crucial for children with hearing loss. Paastch and Toe (2014) noted that the ability to overhear conversation at home and at school, practice turn taking in conversation, and knowing how to maintain conversations was very important. They also stated that hearing technology must allow them to overhear conversation, to increase the opportunities for incidental learning. Figure 3 summarizes the important role of auditory stimulation and input on the development of different skills and functions throughout childhood. Hearing loss can have negative consequences on the growth and maturation of these skills. Since the maturation of basic skills (language skills and auditory perception for example) happen in the early years are essential for the development of higher-order skills (such as emotion perception and recognition) that come later in childhood, early intervention with well-fitted hearing technology is crucial for children with hearing loss. This will provide optimal support for the development of the brain network and its associated skills and functions (see Figure 4 on page 6).



[1]Kral et al., 2000, [2]Tomblin et al., 2015, [3]Chatterjee et al., 2015, [4]Nettan et al., 2017 [5]Paatsch & Toe, 2014, [6]Constantinescu-Sharpe et al., 2017, [7]Dirk & Rieffe, 2019, [8]Hoffman et al., 2015

Figure 3. The important role of hearing and auditory stimulation in the development of different skills and functions throughout childhood. Delayed intervention or suboptimal hearing aid use may negatively impact the typical development of the young hearing brain.

The lives of children and teens with hearing loss

The life experience of children with hearing loss has changed dramatically in the past twenty years. Smaller, more powerful hearing aids with digital technology have given the audiologist more options in addressing hearing loss. Universal newborn hearing screening along with improved hearing technology has reduced auditory deprivation with early fitting of amplification and has allowed favourable speech and language outcomes to be realized (Archbold & Mayer, 2012; Geers et al., 2011; Mayer & Trezek, 2017). The world has also changed significantly in the education of children with hearing loss. Enrolment of children with hearing loss into mainstream classrooms at their neighbourhood schools is increasing, while enrolment into schools for the deaf and congregated classrooms is decreasing (Angelides & Aravi, 2006; Consortium of Research in Deaf Education [CRIDE], 2017). Further contributing to increased enrolment into mainstream schools is legislation directing movement towards social inclusion for children with differing abilities (Antia et al., 2002). Today, most children with hearing loss find themselves at their neighbourhood schools, interacting with hearing classmates and being educated by hearing education professionals (Consortium of Research in Deaf Education [CRIDE], 2017). They spend their day interacting with their hearing friends, classroom teachers, principals, guidance counsellors, volunteer parents and lunchroom supervisors.

Social development and inclusion for children with hearing loss

Developed social skills are extremely important for children starting school. There is evidence to suggest a strong relationship between psychosocial development and a child's academic performance. The school is an important setting for social activity and feelings of inclusion are important for a child's motivation, participation, and achievement (Goodenow, 1993). Children who have experienced secure relationships in the classroom are more likely to view the world as safe and are more ready to explore and learn (Buyse, Verschueren, Verachtert, & Damme, 2009). In addition, research has shown that children and teens with hearing loss are more at risk of social challenges. They are more likely to experience loneliness than their hearing peers and are at risk of delays in cognitive and social cognitive processing, social maladaptation and psychological disorders (Kent, 2003; Warner-Czyz et al., 2015). While parents, students, and teachers believed that social skills of children with hearing loss were important, parents reported that they took longer for them to acquire

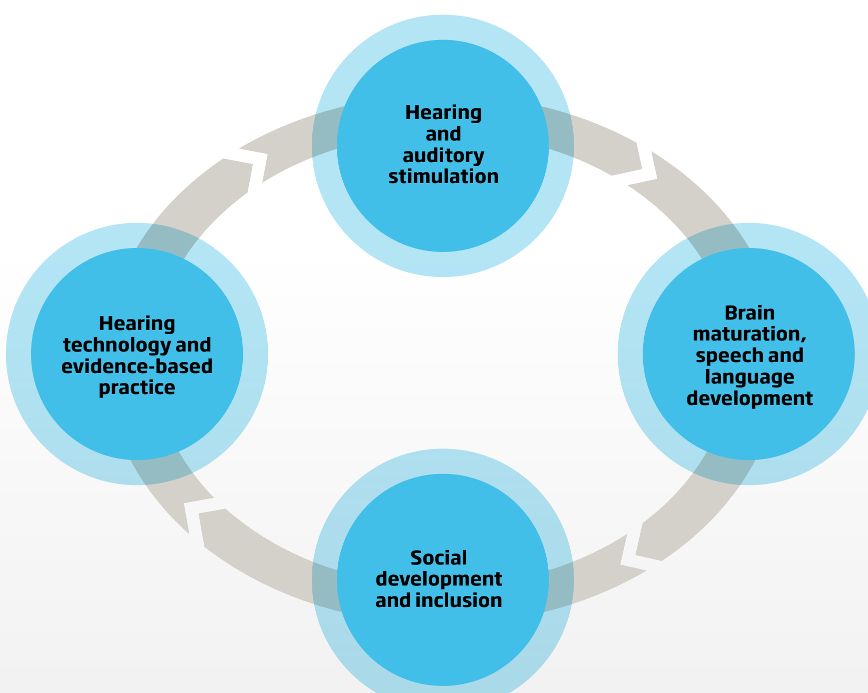


Figure 4. Early intervention and well-fitted hearing technology provide the optimal conditions for learning and development.

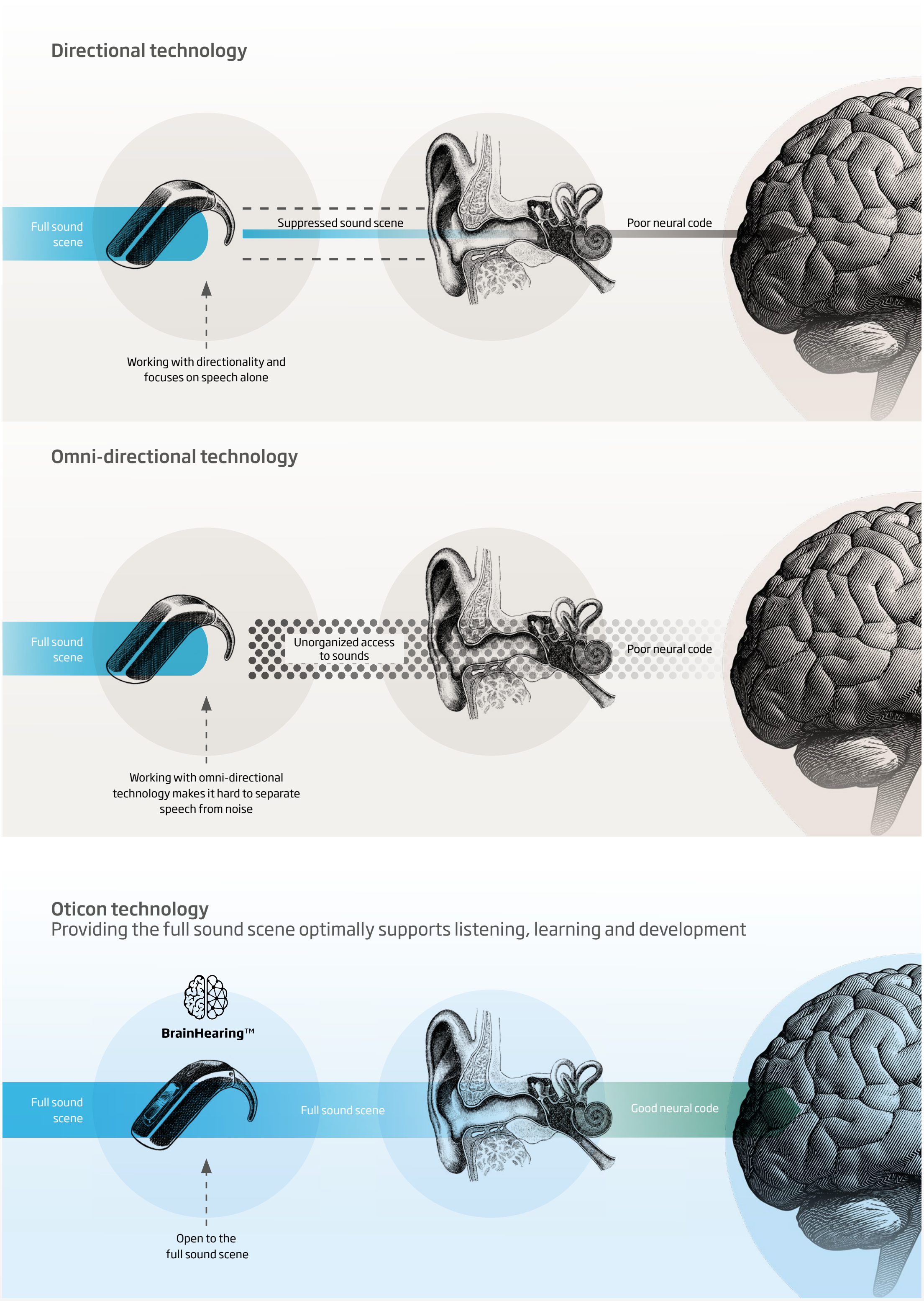


Figure 5. Conventional directional technology limits the sound scene (upper panel). Fixed omni-directional technology does not provide good speech understanding in noise (middle panel). Neither of the strategies provides optimal support to the young brain. Oticon BrainHearing technology is designed to provide the optimal input to the auditory system. This is crucial for brain maturation and for children to to relate and respond to the world around them (lower panel).

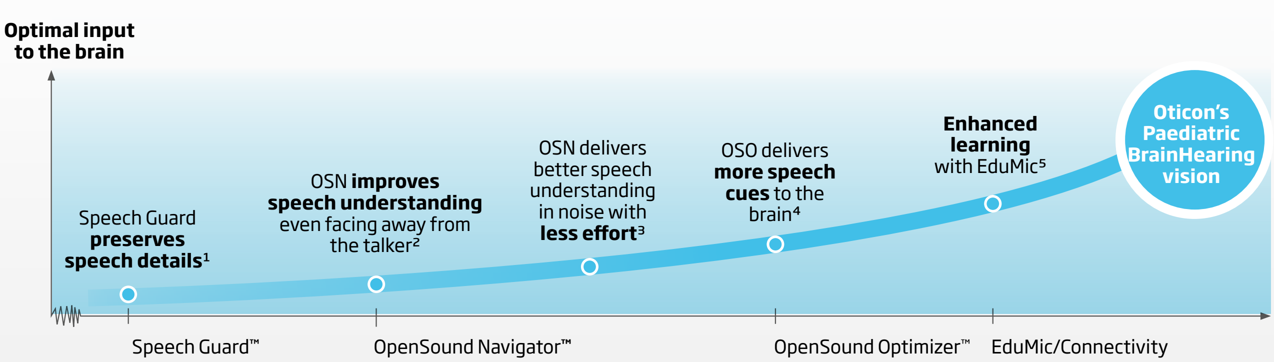
(Gordey, 2018). Parents pre-taught social skills, to better prepare their child for school entry. This included enrolment in sporting and recreational activities and providing other opportunities to practice social skills (Gordey, 2018). These findings highlight the need for parents, educators, and hearing care professionals to address social skill development early, which includes the provision of well-fitted and advanced hearing technology that supports full access to a child's listening environment. While there are many social and academic benefits of inclusion in a general classroom (Eriks-Brophy & Whittingham, 2013), placement alone does not guarantee it. Hearing technology that supports full access to communication is essential to support the inclusion process (Luckner & Ayantoye, 2013).

Oticon technology and support for the brain

For children with hearing loss, it is important to provide sound through amplification that optimally will support the development of the young brain in a timely manner. As discussed in this paper, children need to be exposed to the environment as early as possible to get the stimulation needed for the brain network to mature. Conventional hearing aid amplification strategies such as directionality may reduce access to sounds and limit the audibility of the talker outside the microphone beam. In addition, speech understanding in noise using omnidirectional microphones is usually far from satisfactory. In contrast, Oticon has designed and implemented technology in our hearing aids to give children access to all meaningful sounds in a rich and balanced soundscape. By delivering sounds with optimal gain and clarity to the auditory system, children will be provided with the best possible conditions to grow, develop, learn, live and thrive - from the maturation of the auditory cortex, to freely interacting with their peers. See Figure 5 (on page 7) for the comparisons between the conventional amplification strategies and Oticon technology.

OpenSound Optimizer™ prevents feedback occurrence and substantially reduces the gain reductions during the day. This ensures optimal gain and gives better sound quality and consistent access to speech. By providing up to 6 dB more stable gain, this feature provides the brain with up to 25% more speech cues (estimated based on the Speech Intelligibility Index, ANSI S3.5, 1997, R2002). To further improve access to speech, the adaptive wide dynamic range compression system, Speech Guard™, has been designed and proven to preserve speech detail. Wide dynamic range compression is a hearing aid feature to improve tolerance to loud sounds, and it is well known that fast-acting amplitude compression in hearing aids can negatively affect speech recognition (Souza, 2002), and the perception of high-frequency phonemes is likely influenced by the form of amplification. Pittman et al. (2014) has shown that the adaptive compression strategy used in Speech Guard better preserves the intensity contrasts in a speech signal for the benefit of both children and adults with hearing loss, as compared to the tradition slow- or fast-acting compression.

This has been demonstrated in OpenSound Navigator™, featured in Oticon Opn Play™. It has an environmental sensor and allows more precise detection to changes in the environment in a manner that is superior to traditional technologies. This feature greatly improves speech understanding in noisy environments. Browning et al. (2019) demonstrated that OpenSound Navigator improved speech understanding in noise by an average of 4 dB SNR, when children faced the target speech and when they faced away from the target speech (also see Oticon whitepaper Ng, 2017). OpenSound Navigator gave equal benefit even when the target speech source was off axis. The study also found that OpenSound Navigator preserved non-target speech coming from different directions. This confirmed that OpenSound



[1]Pittman et al., 2004, [2]Browning et al., 2019, [3]Ng et al., 2019, [4]Speech Intelligibility Index ANSI S3.5 1997, R2002, [5]Lewis, in preparation

Figure 6. A trajectory of our BrainHearing benefits.

Navigator preserved access to other talkers in the environment and opportunities for incidental learning. In a second independent research study, results showed that OpenSound Navigator improved speech recognition in both simple and complex listening conditions by up to 5 dB SNR better than when using an omni-directional microphone (Oticon whitepaper Ng et al., 2019). In addition, these children perceived less effort when listening to speech in noise with OpenSound Navigator. Using less effort in a listening task may allow children to allocate more mental resources on other simultaneous tasks such as learning.

Young children acquire new words and everyday knowledge through interacting with family and peers. Formal learning for school-age children typically takes place in educational settings like occupied classrooms, where noise level could be high. The room acoustics is not always optimal because of reverberation and distance can have detrimental effects on speech understanding. The use of remote microphone systems (RMS) can greatly improve the auditory access to the teacher's voice. Research showed that Oticon's digitally modulated RMS improved speech understanding in both noisy and noisy + reverberant acoustic environments for children. (Lewis, in preparation, also see Oticon whitepaper Gordey & Rumley, 2019). In addition, EduMic showed similar benefit to traditional frequency modulated RMS in noisy environments.

Oticon's BrainHearing philosophy views the impact of hearing loss not just from the ear, but also from the perspective of the brain. The brain makes sense of sounds which are important for the maturation of the young brains and the development of cognitive and social skills. Our BrainHearing technology is carefully designed to deliver sounds that give the optimal support for the brain. We have demonstrated through scientific evidence BrainHearing benefits (Figure 6 on page 8). This includes preserving the integrity of sounds, improving speech details, enhancing speech understanding in noise, providing access to speech coming from different directions, and reducing listening effort. With our BrainHearing philosophy, the goal is to have hearing technology that will provide children with optimal input to their auditory system. Oticon strives to give these children hearing technology that supports the best possible conditions to develop and learn and interact with the people they encounter in their everyday lives.

Conclusion

The developing brain is a process that starts before birth and continues through adolescence. Stimulation and early experiences are crucial to how the child's brain network will be wired and established. For children with hearing loss, it is critical that their hearing technology supports this process. Oticon's BrainHearing technology is unique and is designed for today's children with hearing loss and their important listening environments. Different from traditional hearing aid technology, it carefully considers the environment and how to provide the brain with full access to the sound environment. At Oticon, providing hearing technology for children that supports cognitive development, speech and language development, social relationships, and inclusion is at the core of what we do.

References

1. American National Standards Institute (1997, R2002). American National Standard: Methods for Calculation of the Speech Intelligibility Index. Acoustical Society of America.
2. Angelides, P., & Aravi, C. (2006). A comparative perspective on the experiences of deaf and hard of hearing individuals as students at mainstream and special schools. American Annals of the Deaf, 151(5), 476-487. https://doi.org/10.1353/aad.2007.0001
3. Antia, S. D., Stinson, M. S., & Gaustad, M. G. (2002). Developing membership in the education of deaf and hard-of-hearing students in inclusive settings. Journal of deaf studies and deaf education, 7(3), 214-229.
4. Archbold, S., & Mayer, C. (2012). Deaf education: The impact of cochlear implantation?. Deafness & Education International, 14(1), 2-15.
5. Browning, J. M., Buss, E., Flaherty, M., Vallier, T., & Leibold, L. J. (2019). Effects of adaptive hearing aid directionality and noise reduction on masked speech recognition for children who are hard of hearing. American journal of audiology, 28(1), 101-113.
6. Buyse, E., Verschueren, K., Verachtert, P., & Damme, J. V. (2009). Predicting school adjustment in early elementary school: Impact of teacher-child relationship quality and relational classroom climate. The Elementary School Journal, 110(2), 119-141.
7. Chatterjee, M., Zion, D. J., Deroche, M. L., Burianek, B. A., Limb, C. J., Goren, A. P., ... & Christensen, J. A. (2015). Voice emotion recognition by cochlear-implanted children and their normally-hearing peers. Hearing research, 322, 151-162.
8. Cisneros-Franco, J. M., Voss, P., Thomas, M. E., & de Villers-Sidani, E. (2020). Critical periods of brain development. In Handbook of Clinical Neurology (Vol. 173, pp. 75-88). Elsevier.
9. Conel, J.L., 1939–1967. The Postnatal Development of Human Cerebral Cortex, Vol. I–VIII. Harvard University Press, Cambridge, MA.
10. Consortium for Research in Deaf Education (CRIDE). (2017). CRIDE report on 2017 survey on educational provision for deaf children. Retrieved from http://www.ndcs.org.uk/professional_support/national_data/cride.html#contentblock1
11. Constantinescu-Sharpe, G., Phillips, R. L., Davis, A., Dornan, D., & Hogan, A. (2017). Social inclusion for children with hearing loss in listening and spoken Language early intervention: an exploratory study. BMC pediatrics, 17(1), 1-11.
12. Dirks, E., & Rieffe, C. (2019). Are you there for me? Joint engagement and emotional availability in parent–child interactions for toddlers with moderate hearing loss. Ear and hearing, 40(1), 18-26.
13. Eriks-Brophy, A., & Whittingham, J. (2013). Teachers' perceptions of the inclusion of children with hearing loss in general education settings. American annals of the deaf, 158(1), 63-97.
14. Geers, A. E., & Hayes, H. (2011). Reading, writing, and phonological processing skills of adolescents with 10 or more years of cochlear implant experience. Ear and hearing, 32(1), 49S.
15. Goodenow, C. (1993). The psychological sense of school membership among adolescents: Scale development and educational correlates. Psychology in the Schools, 30(1), 79-90.
16. Gordey, D. W. (2018). Teacher-Student Relatedness: The Importance of Classroom Relationships for Children with Hearing Loss.
17. Gordey, D. & Rumley, J. (2019). Enhanced learning with EduMic. Oticon Whitepaper.
18. Hensch, T. K., & Bilimoria, P. M. (2012, July). Re-opening windows: manipulating critical periods for brain development. In Cerebrum: the Dana forum on brain science (Vol. 2012). Dana Foundation.
19. Hoffman, M. F., Quittner, A. L., & Cejas, I. (2015). Comparisons of social competence in young children with and without hearing loss: A dynamic systems framework. Journal of deaf studies and deaf education, 20(2), 115-124.
20. Huttenlocher, P. R., & Dabholkar, A. S. (1997). Regional differences in synaptogenesis in human cerebral cortex. Journal of comparative Neurology, 387(2), 167-178.

21. Kent, B. A. (2003). Identity issues for hard-of-hearing adolescents aged 11, 13, and 15 in mainstream setting. Journal of Deaf Studies and Deaf Education, 8(3), 315-324. https://doi.org/10.1093/deafed/eng017

22. Kral, A., Hartmann, R., Tillein, J., Heid, S., & Klinke, R. (2001). Delayed maturation and sensitive periods in the auditory cortex. Audiology and Neurotology, 6(6), 346-362.

23. Kral, A., & Eggermont, J. J. (2007). What's to lose and what's to learn: development under auditory deprivation, cochlear implants and limits of cortical plasticity. Brain Research Reviews, 56(1), 259-269.

24. Kuhl, P. K. (2004). Early language acquisition: cracking the speech code. Nature reviews neuroscience, 5(11), 831-843.

25. Kuhl, P. K., Tsao, F. M., & Liu, H. M. (2003). Foreign-language experience in infancy: Effects of short-term exposure and social interaction on phonetic learning. Proceedings of the National Academy of Sciences, 100(15), 9096-9101.

26. Lewis, D. Manuscript in preparation.

27. Luckner, J. L., & Ayantoye, C. (2013). Itinerant teachers of students who are deaf or hard of hearing: Practices and preparation. Journal of deaf studies and deaf education, 18(3), 409-423.

28. Mayer, C., & Trezek, B. J. (2018). Literacy outcomes in deaf students with cochlear implants: Current state of the knowledge. The Journal of Deaf Studies and Deaf Education, 23(1), 1-16.Moore, D. R., Hutchings, M. E., & Meyer, S. E. (1991). Binaural masking level differences in children with a history of otitis media. Audiology, 30(2), 91-101.

29. Moore, D. R., Hutchings, M. E., & Meyer, S. E. (1991). Binaural masking level differences in children with a history of otitis media. Audiology, 30(2), 91-101.

30. Netten, A. P., Rieffe, C., Soede, W., Dirks, E., Korver, A. M., Konings, S., ... & DECIBEL Collaborative study group. (2017). Can you hear what I think? Theory of mind in young children with moderate hearing loss. Ear and hearing, 38(5), 588-597.

31. Ng, E. (2017). Benefits of OpenSound Navigator in children. Oticon Whitepaper.

32. Ng, E., Goverts, T., Kramar, S., & Zekveld, A. (2019). Improved speech understanding with less effort in children: An OpenSound Navigator™ study. Oticon Whitepaper.

33. Paatsch, L. E., & Toe, D. M. (2014). A comparison of pragmatic abilities of children who are deaf or hard of hearing and their hearing peers. Journal of deaf studies and deaf education, 19(1), 1-19.

34. Peterson, C. C. (2004). Theory-of-mind development in oral deaf children with cochlear implants or conventional hearing aids. Journal of child psychology and psychiatry, 45(6), 1096-1106.

35. Picou, E. M., Singh, G., Goy, H., Russo, F., Hickson, L., Oxenham, A. J., ... & Launer, S. (2018). Hearing, emotion, amplification, research, and training workshop: Current understanding of hearing loss and emotion perception and priorities for future research. Trends in hearing, 22, 2331216518803215.

36. Pittman, A. L., Pederson, A. J., & Rash, M. A. (2014). Effects of fast, slow, and adaptive amplitude compression on children's and adults' perception of meaningful acoustic information. Journal of the American Academy of Audiology, 25(9), 834-847.

37. Souza, P. E. (2002). Effects of compression on speech acoustics, intelligibility, and sound quality. Trends in amplification, 6(4), 131-165.

38. Stephenson, H., Higson, J., & Haggard, M. (1995). Binaural hearing in adults with histories of otitis media in childhood. Audiology, 34(3), 113-123.

39. Tierney, A. L., & Nelson III, C. A. (2009). Brain development and the role of experience in the early years. Zero to three, 30(2), 9.

40. Tomblin, J. B., Harrison, M., Ambrose, S. E., Walker, E. A., Oleson, J. J., & Moeller, M. P. (2015). Language outcomes in young children with mild to severe hearing loss. Ear and Hearing, 36(0 1), 76S.

41. Walker, E., McCreery, R., Spratford, M., & Roush, P. (2016). Children with auditory neuropathy spectrum disorder fitted with hearing aids applying the American Academy of Audiology Pediatric Amplification Guideline: Current practice and outcomes. Journal of the American Academy of Audiology, 27(03), 204-218.

42. Warner-Czyz, A. D., Loy, B. A., Evans, C., Wetsel, A., & Tobey, E. A. (2015). Self-esteem in children and adolescents with hearing loss. Trends in Hearing, 19. https://doi.org/10.1177/2331216515572615

6172704NZ / 2021.08.20 / v1