Evaluation of a sentence test in noise in children with hearing impairment

Lone Percy-Smith[1], Signe Wischmann[1], Jane Lignel Josvassen[1], Maria Hallstrøm[1], Ariane Laplante-Lévesque[3, 4], Maria Grube Sorgenfrei[3] & Per Caye-Thomasen[2]

ABSTRACT

INTRODUCTION: School-aged children with hearing impairment (HI) listen and learn in noisy environments. On-going monitoring of speech understanding in noise is essential to adjust clinical interventions accordingly.

METHODS: The aim of this study was to assess Dantale II in a paediatric population. The secondary aims were identification of differences and similarities between groups of children with HI and normal hearing and between different hearing technologies; investigation of possible associations between Dantale II and verbal working memory. This was a longitudinal, prospective study comparing groups of children (n = 70) using the Dantale II with five-word sentences and verbal working memory with the Clinical Evaluation of Language Functioning-4.

RESULTS: Dantale II seems clinically feasible from the age of six years. Children with NH outperformed children with HI both on completion of the tests and dB signal-to-noise ratio (SNR) scores. Children with hearing aids outperformed children with CI on dB SNR scores. A significant and moderately strong association between speech understanding in noise and verbal working memory was identified.

CONCLUSIONS: Our study produced knowledge about a new generation of children with HI, who showed potentials not previously described. Future research on cognitive development of paediatric populations with HI is essential, as knowledge from adult populations cannot be transferred directly to paediatric populations.

FUNDING: The project received funding from the Innovation Foundation, the Oticon Foundation, Decibel and The Capital Region of Denmark.

TRIAL REGISTRATION: not relevant.

The introduction of universal neonatal hearing screening, digital hearing aids (HA) and cochlear implants (CI) for paediatric populations with hearing impairment (HI) has improved the life conditions for children with congenital HI. It has been documented that early intervention with fitting of HA by three months of age and enrolment in family-centred auditory verbal intervention by six months of age allow children to close the language gap and develop age equivalent language already at three years of age [1]. However, clinical experience has shown that sensory deprivation in the prenatal period can have a profound and permanent effect on the development on the entire central auditory system [2]. Therefore, it is important to keep monitoring paediatric populations with HI in terms of all aspects of audition and language development [3]. Listening and holding conversations in noisy environments represents a major problem for many people with HI [4]. Noisy environments are, nevertheless, part of children's everyday school life and, therefore, it is of great interest to study how school-aged children with HI perform in noisy environments. Recent research has focused on cognitive hearing science and the cognitive energy involved in the listening process for populations with HI [5-7]. However, little is known about the "new" generation of children with HI with early identification of HI, early treatment with HA/CI and with intensive auditory verbal (re)habilitation. Will they encounter the same listening effort and fatigue as reported by adult populations with HI [6]? Most children with HI attend regular schools, where noise and distance to speakers are an inevitable part of a regular school day [8, 9].

The present study is part of a larger project "IHEAR – in school with hearing impairment" with the overall vision: No child with HI left behind. This vision is understood in broad terms and incorporates areas of audition/listening, speech, language, cognition and social well-being. The research unit of Decibel [10] is the principal investigator of the project and works in partnerships with Oticon/Oticon Medical, Rigshospitalet, Aarhus University Hospital and the Capital Region of Denmark. The primary aim of the present study was to investigate whether children with normal hearing (NH) and HI can perform the speech recognition test Dantale II – a Danish sentence-based test of speech perception – in noise. Dantale II is a well-known clinical tool in Denmark but is seldomly used for paediatric populations, even though the original study stressed that Dantale II can be used with children who are able to memorize five-word sentences [4]. A secondary aim was to identify differences and similarities between children with NH/HI and between children with HA/CI and track developments over a two-year period. Furthermore, the study investigated possible associations between Dantale II and verbal working memory, as

ORIGINAL ARTICLE

1) Decibel, Hellerup, Denmark
2) Department of Oto-rhino-laryngology, Head and Neck Surgery, Rigshospitalet, Denmark
3) Oticon Medical, Denmark
4) Behavioral Sciences and Learning, Linköping University, Sweden

Dan Med J 2020;67(1):A06190358

TABLE 1 / Characteristics of recipients..

	Children with HA (N = 14)		Children with CI (N = 32)		Children with NH (N = 24)	
	n (%)	age, yrs, mean (± SD)	n (%)	age, yrs, mean (± SD)	n (%)	age, yrs, mean (± SD)
Gender						
Boy	12 (86)	-	16 (50)	-	12 (50)	-
Girl	2 (14)	-	16 (50)	-	12 (50)	-
Dantale[a] II						
Year 1	14	6.4 (± 1.1)	32	6.6 (± 1.2)	24	7.4 (± 1.6)
Year 2	14	7.5 (± 1.0)	32	7.7 (± 1.3)	24	7.4 (± 1.6)
CELF						
Year 1	13	6.8 (± 1.0)	27	7.0 (± 1.2)	-	-
Year 2	13	7.5 (± 1.2)	24	7.7 (± 1.2)	-	-

CELF = Clinical Evaluation of Language Functioning; CI = cochlear implant; HA = hearing aid; NH = normal hearing; SD = standard deviation.
a) Danish Hagerman sentences system.

verbal working memory has been reported to be a challenge for populations with HI [11, 12].

METHODS

The main project design is prospective, longitudinal and comparative, and is conducted from January 2017 to December 2020. The project includes annual testing of functional hearing using the Dantale II in 2017, 2018 and 2019. The present study investigated results from the first two annual tests and compared Dantale II scores with a test of verbal working memory.

Dantale II

Speech audiometry refers to procedures that use speech stimuli to assess auditory function [13]. The speech recognition threshold (SRT) is an estimate of the presentation level at which an individual can identify speech stimuli 50% of the time. Monosyllabic words are typically presented to determine SRT in quiet. The most commonly used speech audiometry in Denmark is SRT using the Dantale I monosyllabic word lists. Sentences are typically used to measure the signal-to-noise ratio (SNR) at which an individual identifies stimuli 50% of the time. Dantale II consists of 15 lists each with ten sentences. Each sentence has the same syntactical structure and contains five words: name, verb, numeral, adjective and object (e.g. Anders ejer ti gamle jakker) but no semantic cues, which provides a low probability and a high reliability [4]. Each sentence is generated by a random combination of the alternatives from a base list (closed-set). In the present set-up speech (target) and noise (masker) came from the same loudspeaker (Genelec 8040A) located at 0°. The test is sensitive with an adaptation towards 50% correct and a psychometric function most steep around 40-50% correct. The target level was 70 dB sound pressure level (SPL)(C) which represented a realistic speech level in noisy environments. The masker level started at 60 dB SPL(C) and the masker type was speech-shaped unmodulated noise, e.g. steady state noise shaped as the long-term spectrum of speech. All children were trained before running the test. This training familiarised the children with the speech test material and with the task of listening to five-word sentences. Test procedure was as follows: 1) Training part 1: ten sentences without noise, target speech at 65 dB(C). 2) Training part 2: 20 sentences with adaptive noise as in test. 3) Test part 1: 20 sentences with adaptive noise. 4) Test part 2: 20 sentences with adaptive noise. The score is defined as a mean of test 1 and 2 and is expressed in dB SNR, where a negative value indicates a better result. Testing was performed at Oticon headquarters and all children were accompanied by at least one parent. No adjustments of the setting of the child's HA/CI were made. To make the test more child-friendly, it was renamed the "parrot test": a parrot was placed above the loudspeaker and children were to do just like parrots, e.g., repeat what they had heard. From a pilot phase it became clear that the names the test includes (Ingrid, Michael, Linda, Ulla, Niels, Henning, Anders, Kirsten, Per and Birgit) were not known to all children and therefore the training was introduced by a story mentioning these names so that the children became familiar with them.

TABLE 2 / Comparisons of Dantale[a] II test scores for children in the hearing impairment group and children in the normal hearing group.

	Year 1						Year 2					
Group	n	median (± IQR)	W statistic	Z	p-value	ES	n	median (± IQR)	W statistic	Z	p-value	ES
Hearing impairment												
Children with CI	13	−1.0 (± 4.5)	30	−2.6	0.007	−0.60	26	−1.7 (± 3.8)	179.5	−2.4	0.02	−0.38
Children with HA	6	−3.5 (± 1.3)					13	−4.1 (± 3.3)				
Normal hearing												
Children with HI	19	−1.9 (± 4.8)	541.5	3.7	< 0.0001	0.58	39	−2.0 (± 4.4)	411.5	−4.1	< 0.001	−0.52
Children with NH	22	−4.9 (± 1.9)					22	−4.9 (± 1.9)				

CI = cochlear implant; ES = effect size; HA = hearing aid; HI = hearing impairment; IQR = interquartile range; NH = normal hearing.
a) Danish Hagerman sentences system.

Verbal working memory

Verbal working memory was tested with the standardised test Clinical evaluation of language fundamentals, Clinical Evaluation of Language Functioning (CELF)-4 [14]. Verbal working memory is tested by use of digit span and well-known sequences. The children had to repeat digits forwards and backwards and to say the alphabet while counting e.g., A1, B2, C3 etc. The scores were added and calculated to form a single index score.

Material

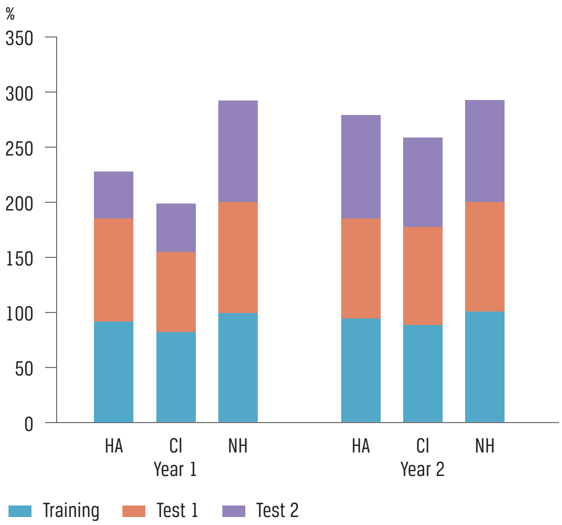
A total of 70 preschool/school children aged 4-10 years were included in the study group (n = 46 with HI and n = 24 with NH). Children with HI used hearing technology from various manufacturers. The inclusion criteria for children with HI were: prior to IHEAR three years of auditory verbal therapy (AVT), provided by AV-practitioners who were certified in AV practice or who had completed the three-year AV education at the AG Bell Academy for Listening and Spoken Language [15].
A total of 54 children with HI and their families fulfilled the criteria and 47 accepted (participation rate = 87%). No common denominator was found for the six children/families who declined in terms of gender, age and technology. In all, 42 children were part of an AVT-project prior to IHEAR [16] and were recruited from there. Five children were recruited from a local AV programme. The children were from the Nordic countries but with a majority from Zealand (n = 39), Jutland (n = 5), the Faroe Islands (n = 1), Sweden (n = 1), Norway (n = 1). One child with bone anchored hearing aids was excluded in the present study but will instead be used as a case study. A comparison group counting 24 children with NH was established. The age range of the group was 4-10 years. They were children of colleagues in Decibel/Oticon/Rigshospitalet as well as siblings and classmates of the participating children with HI.

Data analysis

Descriptive statistics were summarised as frequencies and percentages and as means ± standard deviation and interquartile range for the continuous variables. The Shapiro-Wilk's test was used to assess the normality of distribution of investigated parameters. The Dantale II values were analysed as the mean value of test 1 + 2 dB SNR. Differences in Dantale II values between groups were analysed by the Wilcoxon (Mann-Whitney) test, as data were not normally distributed. Effect sizes were calculated as $r = \frac{Z}{\sqrt{n}}$. Spearman's correlation was used to analyse the association between Dantale II test scores and CELF-4 scores. Children who had missing data on either of the tests were excluded from all analyses. Independent two-sample t-tests were run to investigate age differences in children who had missing test scores versus children who completed the tests. p-values below 0.05 were considered statistically significant. Statistical analyses were performed using SAS software 9.4 (SAS Institute, Cary, NC).

Trial registration: not relevant.

FIGURE 1 / Percentage of children completing training, test 1 + 2.



CI = cochlear implant; HA = digital hearing aid; NH = normal hearing.

Results

Table 1 summarises characteristics of recipients in terms of age at test, gender and hearing technology. **Table 2** summarises test statistics, p-values and effect sizes. **Figure 1** summarises the percentage of completion of training and test 1 + 2. At year one, the percentage of children with HA/CI who completed test 2 was lower than that of children with NH, 42%, 44% and 92% respectively. At year two, markedly more children with HA/CI completed test 1 + 2, 93%, 81%, and 92%, respectively. Two-sample t-tests revealed that children who did not complete both tests at year one and two were significantly younger (year one: t = –4.0, n = 46, p = 0.0002) and (year two: t = –2.0, n = 46, p = 0.05).

Children with HA outperformed children with CI at a significant level both years, p = 0.007 and p = 0.02, respectively. The NH group significantly outperformed the HI group in both years: Year one (W = 541.5, Z = 3.7, p < 0.0001), year two W = 411.5, Z = –4.1, p < 0.01).

Table 3 summarises the results of the CELF-4 compared to Dantale II. Results of the Spearman's correlation indicated a significant and moderately strong association, e.g. a better score on Dantale II (negative values) was associated with a better score on the

TABLE 3 / Spearman's correlation between Dantale[a] II test scores and Clinical Evaluation of Language Functioning test scores in the group of children with hearing impairment.

Year	n	r	p-value
1	19	-0.5	0.02
2	33	-0.4	0.01

a) Danish Hagerman sentences system.

CELF-4 for both year one and two: r = –0.5, p = 0,002/r = –0.4, p = 0.001, respectively.

DISCUSSION

We found that children aged 4-10 years can complete the Dantale II. The Dantale II provides a more realistic measure of everyday performance than measures of speech understanding in noise where isolated monosyllabic words are used as target speech. Running speech in the presence of noise better reflects realistic listening situations for populations with HI and may be used as part of the lifelong assessment of a person's hearing status and technology. Children with HI of school age must follow academic curriculums and learn to socialise, and this generally occurs in the presence of noise. It is, therefore, important that their performance is evaluated as close to everyday life situations as possible. We found a significant association between age and completion of Dantale II tests 1 + 2 and this information has clinical impact as it seems more feasible to use the test from around six years of age. It would be relevant to prepare an adapted version of Dantale II targeting the youngest children and to elaborate further on as a user-operated speech-in-noise test for paediatric populations [17]. Dantale II can be used in a three-word sentence format which might be appropriate for testing paediatric populations but to the best of our knowledge, there is no documentation to support this use. Therefore, future studies comparing three-word sentences to five-word sentences would be relevant to perform. It would also be relevant to try out Dantale II when speech and noise are spatially separated, which would resemble more realistic listening situations. Spatial separation of the source (speech) and masker (noise) might have led to different results compared with our co-located set-up due to two phenomena: spatial unmasking as well as the hearing devices having directional microphones. We found a positive development from year one to year two and it is questionable whether this effect was due to; age, a learning effect [18], change of CI/HA technology or cognitive taxing. Our data sample was too small to adjust statistically for these variables with regression analysis, but it would be highly relevant to investigate these variables in future studies. Moreover, we used stationary noise, modulated noise (e.g., International Collegium of Rehabilitative Audiology noise) could have produced different results. Modulated noise better reflects the spectral and temporal characteristics of the sound of everyday life and therefore future studies should consider using modulated noise as masker [19].

Our results relate to the latest knowledge on cognitive hearing science [5, 6, 12]. Children with HI were challenged in completing the tests in the first year and despite an improvement at year two, children with HI performed significantly poorer than children with NH. It may be argued that this finding was due to effortful listening and a lack of motivation to listen because it was simply too hard. Even at higher ages, children with HI perform poorer than children with NH, most likely because of a poorer signal in background noise, which taxes cognitive processes. Against this argument is the performance of children with HA compared to children with NH at year two, scores were largely similar, –4.1 dB SNR and –4.7 dB SNR, respectively. This is an interesting finding and promises a bright "listening future" for the new generation of children with HI. Moreover, because of the unknown potentials of the new generation of children with HI it is important that the interplay between hearing and cognition involves paediatric populations, as knowledge from adult HI populations cannot be transferred directly to paediatric populations. Working memory has been reported to challenge children with HI [11, 12]. We found a significant and moderately strong association between Dantale II and verbal working memory. However, this association does not provide information about the casual pathway and the question remains whether children with HI struggle to hear and hence use all their cognitive resources for perception and have little left for memory? Or whether poorer working memory causes poorer Dantale II scores?

CONCLUSIONS

Our study produced knowledge about a new generation of children with HI, showing potentials which have not previously been described. It is therefore important to keep studying the potentials and outcomes of this generation to adjust clinical interventions accordingly.

CORRESPONDENCE: *Lone Percy-Smith.* E-mail: lone@decibel.dk
ACCEPTED: 14 November 2019

CONFLICTS OF INTEREST: none. Disclosure forms provided by the authors are available with the full text of this article at Ugeskriftet.dk/dmj

ACKNOWLEDGEMENTS: The authors wish to express their gratitude to *Jeanette Hølledig Mikkelsen* and *Lena Nissen* for testing; *Anne-Marie Caron, Caroline Ekelund, Christina Maas* and *Susan Pihl Lassen* for audiometry; *Christian Stender Simonsen* and *Søren Kamaric Riis* for data analysis.

LITERATURE

1. Fulcher A, Purcell A, Baker E et al. Listen up: children with early identified hearing loss achieve age-appropriate speech/language outcomes by 3 years-of-age. Int J Pediatric Otorhinolaryng 2012;76:1785-94.

2. Uhlén I, Engström E, Kallioinen P et al. Using a multi-feature paradigm to measure mismatch responses to minimal sound contrasts in children with cochlear implants and hearing aids. Scand J Psychol 2017;58:409-21.
3. Ching TYC, Dillon H, Leigh G et al. Learning from the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study: summary of 5-year findings and implications. Int J Audiol 2018;57(suppl2):S105-S111.
4. Wagener K, Josvassen JL, Ardenkjaer R. Design, optimization and evaluation of a Danish sentence test in noise. Int J Audiol 2003;42:10-7.
5. Rönnberg J, Holmer E, Rudner M. Cognitive hearing science and ease of language understanding. Int J Audiol 2019;58:5.
6. Pichora-Fuller MK, Kramer SE, Eckert MA et al. Hearing impairment and cognitive energy: The framework for Understanding Effortful Listening (FUEL). Ear Hearing 2016;37(suppl1):5S-27S.
7. Arlinger S, Lunner T, Lyxell B et al. The emergence of cognitive hearing science. Scand J Psychol 2009;50:371-84.
8. Ganek H, Robbins MA, Niparko JK. Language outcomes after cochlear implantation. Otolaryngo Clin North Am 2012;45:173-85.
9. Rekkedal AM. Teachers' use of assistive listening devices in inclusive schools, Scandinavian Journal of Disability Research 2014;16:4:297-315.
10. Decibel – Landsforeningen for børn og unge med høretab. www.decibel.dk (1 Jan 2019).
11. Kronenberger WG, Henning SC, Ditmars AM et al. Verbal learning and memory in prelingually deaf children with cochlear implants. Int J Audiol 2018;57:746-54.
12. Kronenberger WG, Henning SC, Ditmars AM et al. Language processing fluency and verbal working memory in prelingually deaf long-term cochlear implant users: a pilot study. Cochlear Implants Int 2018;19:312-23.
13. Katz J, Chasin M, Hood LJ et al. Handbook of clinical audiology 7 ed. Chapter 5. Copenhagen: Wolters Kluwer, 2015.
14. Semel E, Wiig EH, Wayne AS. Clinical evaluation of language fundamentals 4 ed. Pearson. Art no. 370020.
15. AG Bell. www.listeningandspokenlanguage.org (1 Jan 2019).
16. Percy-Smith L, Hallstrøm M, Josvassen JL et al. Differences and similarities in early vocabulary development between children with hearing aids and children with cochlear implant enrolled in 3-year auditory verbal intervention. IJPORL 2018;108:67-72.
17. Pedersen ER, Juhl PM. User-operated speech in noise test: Implementation and comparison with a traditional test, Int J Audiol 2014;53:336-44.
18. Dreschler WA, Verschuure H, Ludvigsen C et al. ICRA Noises: artificial signal with speech-like spectral and temporal properties for hearing instrument assessment. Audiology 2001;40:148-57.
19. Hernvig LH, Olsen SO. Learning effect when using the Danish Hagerman sentences (Dantale II) to determine speech reception threshold. Int J Audiol 2005;44:509-12.