# The Feasibility and Reliability of a Digits-in-Noise Test in the Clinical Follow-Up of Children With Mild to Profound Hearing Loss

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**Objectives:** Speech perception in noise is an important aspect of the rehabilitation of children with hearing loss. We aimed to evaluate the feasibility and reliability of the Dutch digits-in-noise (DIN) test in the clinical follow-up of children with hearing aids (HAs) and/or cochlear implants (CIs). A second aim of the study was to gain insight in the speech perception in noise performance of children with different degrees of hearing loss.

**Design:** We retrospectively analyzed DIN test data of Dutch-speaking children with hearing loss (N = 188; 5 to 18 years old). A free-field version of the DIN-test was used. Children with open-set phoneme recognition in quiet of >70% at 65 dB SPL (best aided condition) were included. Ages ranged from 5 to 18 years old. All were experienced HA or CI users and had used their device(s) for at least 1 year before the measurement in the study. The DIN-test was performed in the framework of a clinical rehabilitation program. During testing, children wore their own devices with normal daily programs.

**Results:** The average speech reception threshold (SRT) was −3.6 dB (SD 3.6) for the first list and significantly improved to −4.0 dB (SD 3.1) for the second list. HA users had a 4-dB better SRT compared with CI users. The larger the child's hearing loss, the worse the SRT is. However, 15% of the children who completed a first list of 24 trials were unable to complete a second list. Mean adaptive staircase trajectories across trials suggested that learning occurred throughout the first list, and that loss of sustained attention contributed to response variability during the second list.

**Conclusion:** The DIN test can be used to assess speech perception in noise abilities for children with different degrees of hearing loss and using HAs or CIs. The children with hearing loss required a higher signal-to-noise ratio (SNR) than did normal-hearing children and the required SNR is larger as the hearing loss increases. However, the current measurement procedure should be optimized for use in standard pediatric audiological care, as 15% of the children were unable to conduct a second list after the first list to reach a more stable SNR.

**Key words:** Children, Cochlear implants, Hearing aids, Speech in noise.

(Ear & Hearing 2021;42;973–981)

## INTRODUCTION

Early rehabilitation and improvements in hearing aid (HA) and cochlear implant (CI) technology over the past decades have led to better outcomes in the management of children with hearing loss (De Raeve et al. 2015; Tomblin et al. 2015; Dettman et al. 2016; Ching et al. 2018). A useful outcome measure to assess the effectiveness of rehabilitation is speech intelligibility. As outcomes have improved over time, aided speech recognition in quiet listening situations is usually adequate. However, many children have trouble in more challenging listening situations (Hillock-Dunn et al. 2015; Ching et al. 2018; Moore et al. 2020). The assessment of speech recognition in noise abilities provides a better approximation of auditory functioning in real-world environments.

Many tests exist for assessing speech intelligibility in noise which vary in complexity of the target speech, level of context, signal-to-noise ratio (SNR), and presentation level (Plomp & Mimpen 1979; Nilsson et al. 1994; Kollmeier & Wesselkamp 1997; Killion et al. 2004; Nielsen & Dau 2009; Houben et al. 2014). Nevertheless, many of these speech-in-noise-tests cannot be used for (young) children. In the Netherlands, the most used speech-in-noise test—developed by Plomp and Mimpen (1979) and Versfeld et al. (2000)—is too complex for children under 12 years of age because an advanced language competency is required to complete the test. Sentence tests also rely on memory and linguistic aspects, and are not solely a measure of peripheral hearing. In 2013, Smits et al. (2013) developed a digits-in-noise (DIN) test as an alternative to the standard Dutch speech-in-noise test. Because the use of a closed-set paradigm with easy and familiar digit triplets, the effects of top-down processes such as linguistic skills were limited. The DIN test has been proven feasible, reliable and valid for assessing the speech recognition abilities of adults with mild to severe hearing loss (Kaandorp et al. 2015). The test had been widely used in international research projects, but primarily focusing on adults (Jansen et al. 2010; Zokoll et al. 2013; Moore et al. 2014; Brown et al. 2019; De Sousa et al. 2020). Denys et al. (2018) investigated the use of a digit triplet test in children as a school-age hearing screening instrument. They concluded that reliable SRTs could be obtained with this test in children from 9 to 16 years of age. Koopmans et al. (2018) investigated the use of the Dutch DIN test in normal-hearing children from 4 to 12 years old. They concluded that speech perception in noise can accurately and reliably be assessed with the DIN test in children of this age range and that performance is gradually improving with increasing age.

Aside from developmental aspects, hearing loss is known to affect the SRT. Earlier research has shown that children with

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and text of this article on the journal's Web site (www.ear-hearing.com).

<zdoi; 10.1097/AUD.0000000000000989>

hearing loss who use an HA or a CI need a more favorable SNR than do normal-hearing children (Gravel et al. 1999; Litovsky et al. 2006; Scollie et al. 2010; Misurelli & Litovsky 2012; Leibold et al. 2013; Hillock-Dunn et al. 2015; Lewis et al. 2016; Moore et al. 2020). To the best of our knowledge, only three studies assessing speech perception in noise included children fitted with a HA or CI with a wide range of hearing losses (Caldwell & Nittrouer 2013; Nittrouer et al. 2013; Ching et al. 2018). Caldwell and Nittrouer (2013) assessed this in 54 children attending kindergarten, of whom 65% had a sensorineural hearing loss. As expected, the latter children performed less well on speech recognition in noise, than did the children with normal hearing. Nittrouer et al. (2013) studied 113 children, of whom 58% with sensorineural hearing loss. Compared with normal-hearing children, the children with hearing loss scored worse on speech perception in noise. That study also found a significant difference between children using HAs and children using CIs, with the latter children performing worse. The study of Ching et al. (2018), included 252 five-year-old children with prelingual hearing loss, ranging from mild to profound. To achieve the same level of speech perception, the children using CIs required a more favorable SNR of 2 dB than the children using HAs. For the latter children, the degree of hearing loss was not a significant predictor of their speech perception in noise performance.

Until now, the DIN test has not yet been evaluated in a clinical population of children with hearing loss. Because DIN performance in adults has limited influences of top-down processes (e.g. Moore et al. 2014), the SRT might be more representative of peripheral auditory-processing abilities. It may also lead to more consistent outcomes, even in young children, who appear to produce consistent results with the DIN test (Denys et al. 2018; Koopmans et al. 2018). This makes it a potentially powerful pediatric test to assess speech understanding in noise. However, a clinical population is different from normal-hearing children, with regard to comorbidity, behavioral disorders, and cognitive development, even with regard to for children with mild hearing loss (le Clercq et al. 2019; Wang et al. 2019). In the clinical situation, there might not be enough time to adequately explain test procedures, and for retesting in the case of unreliable measurements, etc. In the current study, we evaluated the feasibility and reliability of a free-field version of the DIN test in the clinical follow-up of aided children of different ages, aimed at gaining insight in the speech in noise abilities of these children with different degrees and types (sensorineural or conductive) of hearing loss.

## MATERIALS AND METHODS

### Participants

Data of 188 Dutch-speaking children with hearing loss and fitted with HAs or CIs were collected between June 2018 to October 2019 (n = 188). The children were under treatment at either the Erasmus University Medical Centre—Sophia's Children's Hospital (n = 148) or the Auris Audiological Centre in Rotterdam (n = 40). Children with open-set speech recognition in quiet of >70% at 65 dB SPL were included. Ages ranged from 5 to 18 years old. All were experienced HA or CI users; they had been using the device for at least 1 year before the measurement in the study (see Table 1 for more details). The CI was either a Cochlear (Nucleus 6, Nucleus 7, or Kanso I) or Advanced Bionics (Naida Q70 or Naida Q90) device. The children with HAs were fitted with conventional HAs of different brands. This study was conducted according to the principles of the Declaration of Helsinki (64th WMA, 2013) and the General Data Protection Regulation (Association 2001; Schermer, Hagenauw, & Falot n.d.).

**TABLE 1. Demographic characteristics of the participants**

| Characteristics | Cochlear implant (n = 66) | Hearing aid (n = 122) |
|---|---|---|
| Gender | | |
| Male | 33 (50%) | 62 (51%) |
| Female | 33 (50%) | 60 (49%) |
| Age (yrs) | | |
| Mean (SD) | 11.8 (3.6) | 11.2 (3.0) |
| Hearing Loss (PTA$_{0.5–4\ kHz}$, *better ear*) | | |
| Normal (≤20 dB HL) | 0 | 19 (15%) |
| Mild (21–40 dB HL) | 0 | 30 (25%) |
| Moderate (41–60 dB HL) | 4 (6%) | 58 (47%) |
| Severe (61–80 dB HL) | 8 (12%) | 14 (12%) |
| Profound (>80 dB HL)* | 54 (82%) | 1 (1%) |
| Speech perception in quiet (65 dBSPL, %) | | |
| Mean (SD) | 91 (5.4) | 97 (2.7) |
| Nature of the hearing loss | | |
| Conductive | 0 | 23 (19%) |
| Mixed | 1 (1%) | 8 (6%) |
| Sensoneural | 67 (96%) | 91 (75%) |
| Neural (ANSD) | 2 (3%) | 0 |
| Age at onset of hearing loss | | |
| Prelingual (<3 yrs) | 57 (67%) | 55 (45%) |
| Postlingual (>3 yrs) | 9 (13%) | 67 (55%) |
| Hearing device | | |
| Bilateral | 29 (42%) | 103 (84%) |
| Unilateral | 25 (40%) | 19 (16%) |
| Cochlear implant and hearing aid | 12 (18%) | |

**For prelingual deaf children obtained with brainstem evoked response audiometry before surgery, as a measure for the preimplant condition of the ear.*

### General Procedures

Pediatric audiologists had fitted each child's daily HA or CI program as part of the clinical routine before study participation. All children had a stable program which they used daily. The children used this program during the test sessions, wearing their own device.

Testing was performed in a free-field test setup in a sound-attenuated booth using a clinical audiometer (Decos audiology workstation, version 210.2.6, or Interacoustics AC40). Speech audiometry was conducted with a single loudspeaker. Participants were seated one meter in front of it. For the DIN test, the S0N0 condition was used: the signal and the noise were presented from the same loudspeaker at 0° azimuth in the horizontal plane, comparable with the DIN study of Kaandorp et al. (2015).

### Hearing Loss Assessment

For children fitted with HAs or bimodal CI users, pure-tone audiograms had been obtained during clinical appointments. Hearing thresholds were measured with a clinical audiometer, calibrated according to ISO standard 389-1. In this study, we used the pure-tone air conduction averaged over the frequencies of 0.5, 1, 2, and 4 kHz of the best ear (PTA0.5$_{-4}$). All thresholds were measured according to the shortened ascending method based on ISO standard 8253-1, which means that thresholds were defined by the intensity level at which the tone was heard in two out of three ascents. For the children with unilateral or bilateral CIs, the degree of hearing loss was determined based on brainstem evoked response audiometry *before* surgery. If no response was detected at 100 dB, a hearing loss of 110 dB was recorded.

### Speech Perception Assessment

Speech perception in quiet was measured with the NVA-list (Bosman & Smoorenburg 1995), which consists of phonetically balanced monosyllabics (consonant-vowel-consonant). The word lists were presented at 65 dB SPL for the best aided condition. As in usual clinical practice, the score of the independent phonemes was determined. For all children with phoneme perception scores of >70% at 65 dB SPL, the DIN test was performed.

Speech perception in noise was tested with the DIN test under the best aided condition, including bilateral and bimodal options for children using a listening device for both ears. The DIN test uses a set of 120 unique digit triplet combinations constructed from the digits 0 to 9 uttered by a male speaker, separated by silent intervals. The stimulus signal was mixed with stationary long-term average speech spectrum masking noise. The noise signal was kept constant at 65 dB SPL during the test. The child's task on each trial was to repeat all three digits correctly after each presented triplet. The speech reception threshold (SRT) was determined by varying the SNR adaptively according to the correctness of the response following the standard one-up one down procedure with a step size of 2 dB. The DIN SRT was calculated by taking the average SNR of trials 5 to 25. When the first triplet was not correctly identified, it was repeated at higher intensities until a correct response was obtained. Only when the first triplet was repeated consistently, a second triplet was presented. The entire test was presented twice using two separate lists of digit triplets. Due to time constraints, it was not possible to have a pause between the two lists. For an extensive description of the test, see Smits et al. (2013).

### Statistics

Statistical analyses were performed using IBM SPSS Statistics version 25. Because the data revealed a normal distribution, parametric tests were used. The Pearson correlation served to analyze the correlation between the first and second measurement, between SRT and degree of hearing loss, and between SRT and age. To analyze differences between the first and second test lists, Bland–Altman plots were used (Bland & Altman 1999). The Bland–Altman plots are commonly used to evaluate the agreement between two different measurements. The Bland–Altman plots allow identification of any systematic difference between the measurements or possible outliers. To measure both the strength of correlation and the agreement between measurements, we calculated the intraclass correlation coefficient (ICC). ICC estimates and their 95% confident intervals were calculated based on absolute-agreement, two-way mixed-effects model. The paired-samples t-test was used to investigate differences between the first and second lists. To test differences between two groups, the independent sample-t-test was used. We used the Benjamini–Hochberg method to control the false discovery rate for multiple comparisons. This method controls the expected proportion of falsely rejected hypotheses (Benjamini & Hochberg 1995).

The variables age, degree of hearing loss, amplification device, and aided speech perception in quiet were entered into a multivariable linear regression analysis. An alpha level of 0.05 was set as the threshold level for significance.

## RESULTS

### Feasibility of the DIN Test

The majority of children could complete the DIN test without noticeable problems and within the given time constraints of the regular clinical appointments. However, for 15% of the children, it was not possible to perform the recommended second list of digits due to concentration or time issues. The characteristics of these children (age, hearing level, aided speech perception at 65 dB SPL, and hearing device) did not significantly differ from those of the group of children who could perform the second list, see Table 1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/A773. However, the average SRT of the first list for the group who could not perform the second list was worse (independent sample t-test, $p = 0.015$). The average SRT was −3.6 dB (SD 3.6) for the first list and significantly improved to −4.0 dB (SD 3.1) in the second run (paired-samples t-test, $t(157) = 3.4$, $p = 0.001$).

### Reliability of the DIN Test

Figure 1 shows a scatter plot of the SRT for each individual participant on List 1 and List 2. The first and second SRTs were highly correlated ($r = 0.9$, $p < 0.01$) and the second SRT had improved for the majority of the participants. As a high correlation does not imply a high reliability, we studied the differences between the first and second SRT using the Bland–Altman method (see Fig. 2). The y axis shows the difference of the two measurements (SRT2 – SRT1) and the x axis represent the second SRT (SRT2). The measurement accuracy was defined by the limits of agreement (2.63 and –3.54 dB). The bias was quantified by the mean difference ($d = 0.45 \pm 1.96\text{SE} = 0.24$). Although the bias confirmed that the second SRT improved on average, this improvement is very small compared with the huge variance in the measurement accuracy. The ICC is 0.893 (95% confidence interval of 0.851 to 0.922), indicating a high reliability.

On the basis of the data of 152 children who completed both the training and test list, we constructed the up-down patterns of the first and second lists averaged over the children (see Fig. 3A). This information was not available for the children measured at the Auris Audiological Centre. Figure 3 shows that on average the SNR did not stabilize during the first run. Besides, in the second run, the SNR seems to became worse from the 10th to 14th triplet on. To investigate whether the degree of hearing loss affected this pattern, we divided the data in three groups of different degrees of hearing loss. Figure 3B shows the patterns for different hearing loss categories. It appeared that the less severe the hearing loss, the more a stable SNR could be reached during the first test run. Again, for the second run, the SNR seemed to become worse from the 10th to 14th triplet on. However, this difference was more pronounced when the hearing loss increases.

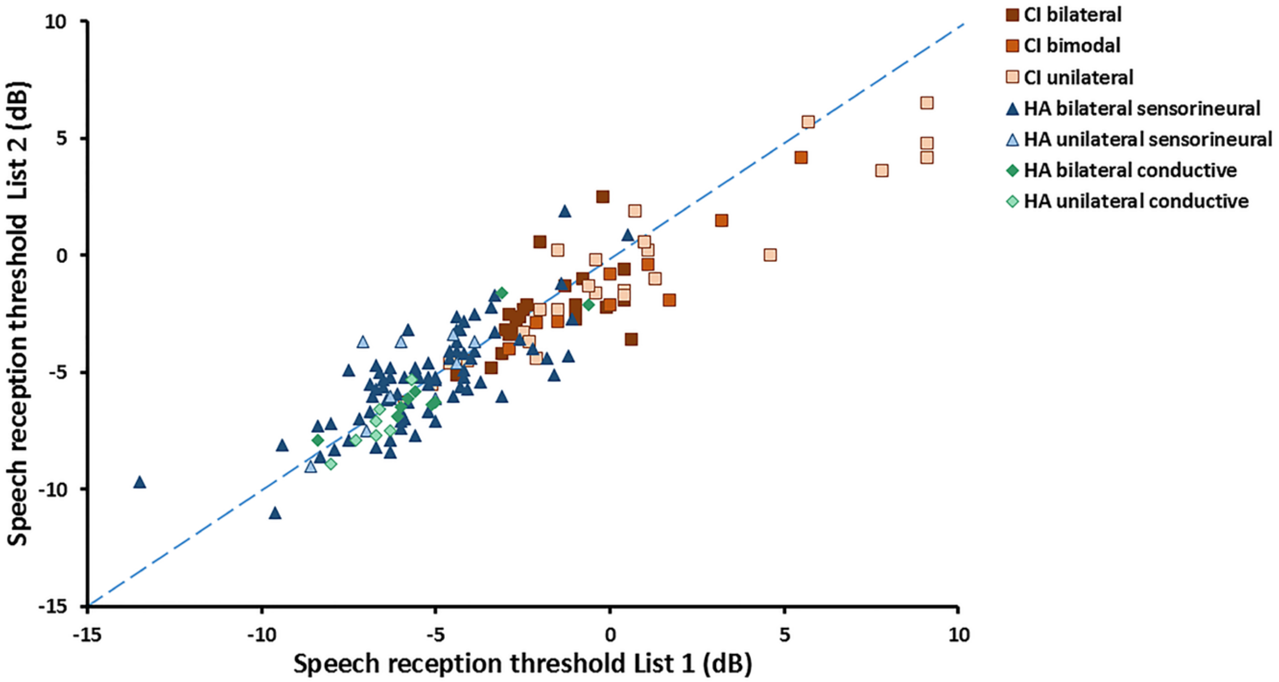

Fig. 1. Speech reception threshold for List 1 on the horizontal axis and List 2 on the vertical axis. Subjects scoring below the dashed line scored better during List 2, whereas subjects above the dashed line scored worse during List 2.

## Outcome of the DIN Test

**Univariate Analysis** • Of the outcome data, only the SRT data for the second list were used (n = 156). Figures 4 and 5 show the results for the SRTs for different degrees of hearing loss for the different devices. In general, the SRT increased as the hearing loss increased ($r = 0.625$, $p < 0.01$). Significant differences in SRT were found between unilateral (−0.7 dB) and bilateral CIs (−2.4 dB) [t-test, $t(47) = -2.2$, $p = 0.04$], between the children with a unilateral HA and conductive (−7.3 dB) and sensorineural hearing loss [−5.3 dB; t-test, $t(14) = -2.4$, $p = -0.03$], and between the HA group (−5.4 dB) and CI group (−1.4 dB) [t-test, $t(159) = 10.2$, $p < 0.01$].

We found a significant association between speech perception in quiet at 65 dBSPL and the SRT ($r = -0.549$, $p < 0.01$). We did not find an association between age and SRT in the studied population ($r = 0.077$, $p = 0.338$). Also by calculating this association

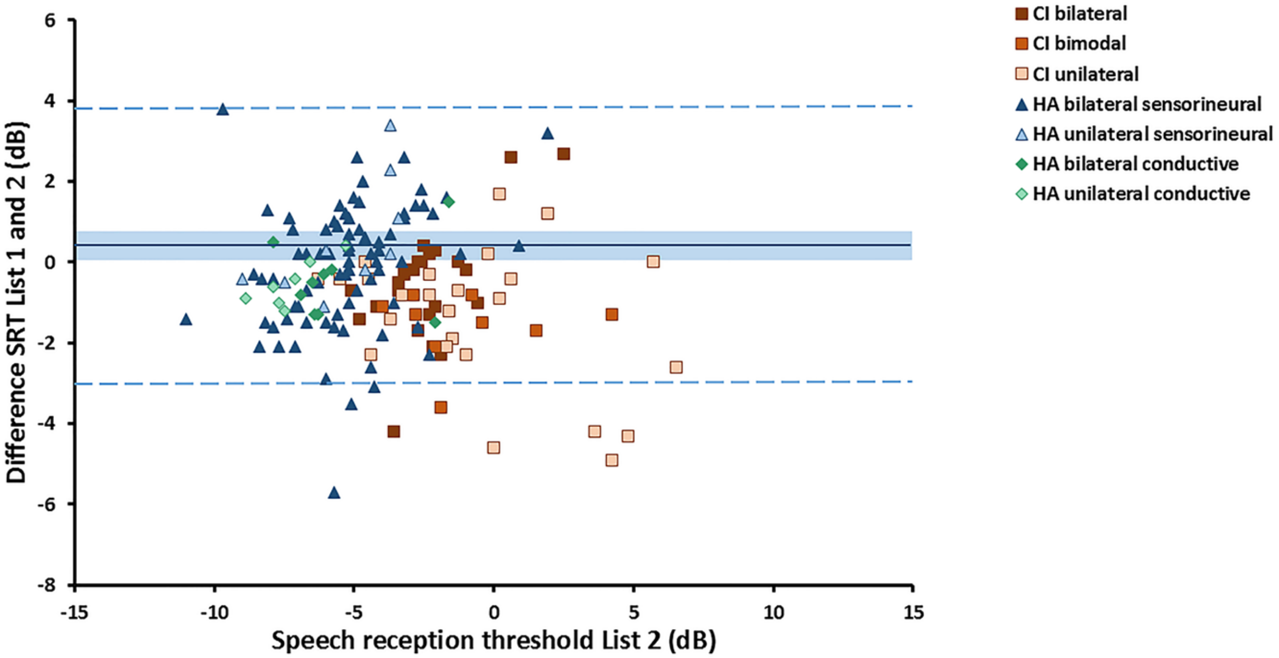

Fig. 2. The difference between the speech reception threshold of Lists 1 and 2 ($SRT_1$–$SRT_2$) against the signal-to-noise ratio of List 2. The dark line denotes the mean difference in SRTs with the light blue area two times the standard error of the mean. The dashed lines denote ±1.96SD of the differences.

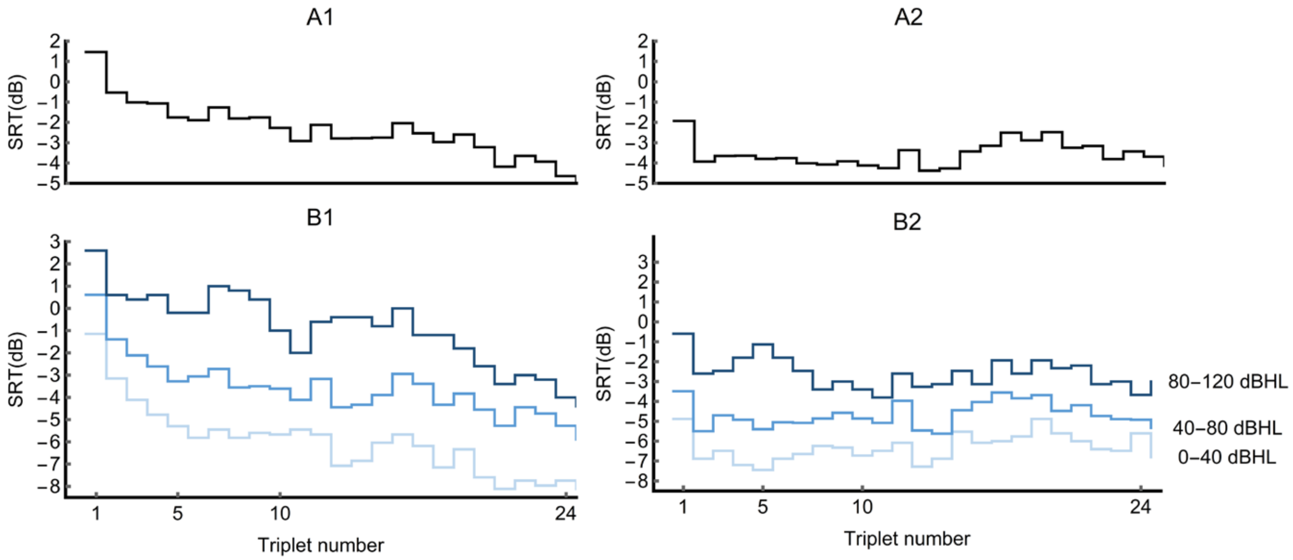

Fig. 3. Up-down pattern of the first (A1) and second (A2) list averaged overall children. B1 and B2 display this pattern per hearing loss category.

for only the children using an HA, no significant association was found between age and SRT ($r = -0.167$, $p = 0.093$). Figure 6 shows the results for the SRTs depending on age. Reported significant $p$ values remained significant after correction for multiple comparisons with the Benjamini–Hochberg method.

**Multivariate Analysis** • We performed a multivariate linear regression analysis on the dependency of the SRT upon age, amplification device, hearing loss, and aided speech perception in quiet. Table 2 provides a summary of the predictors used in the analysis. Significantly associated with SRT were hearing loss ($B = 0.029$, $p = 0.01$) and aided speech perception in quiet ($B = -0.136$ $p = 0.005$). The $R^2$ value of 0.48 indicates that the model explained 48% of the variation in SRT. The model indicated that a larger hearing loss was associated with a worse SRT. Also, a better score for speech perception in quiet was associated with a better SRT. Chronological age and type of amplification device had no significant relation with the SRT. Variables scored low on multicollinearity (variance inflation factor < 5).

## DISCUSSION

### Feasibility of the DIN Test for Children With Hearing Loss

We investigated the feasibility of the DIN test in the clinical follow-up of children with hearing loss (n = 188). It was

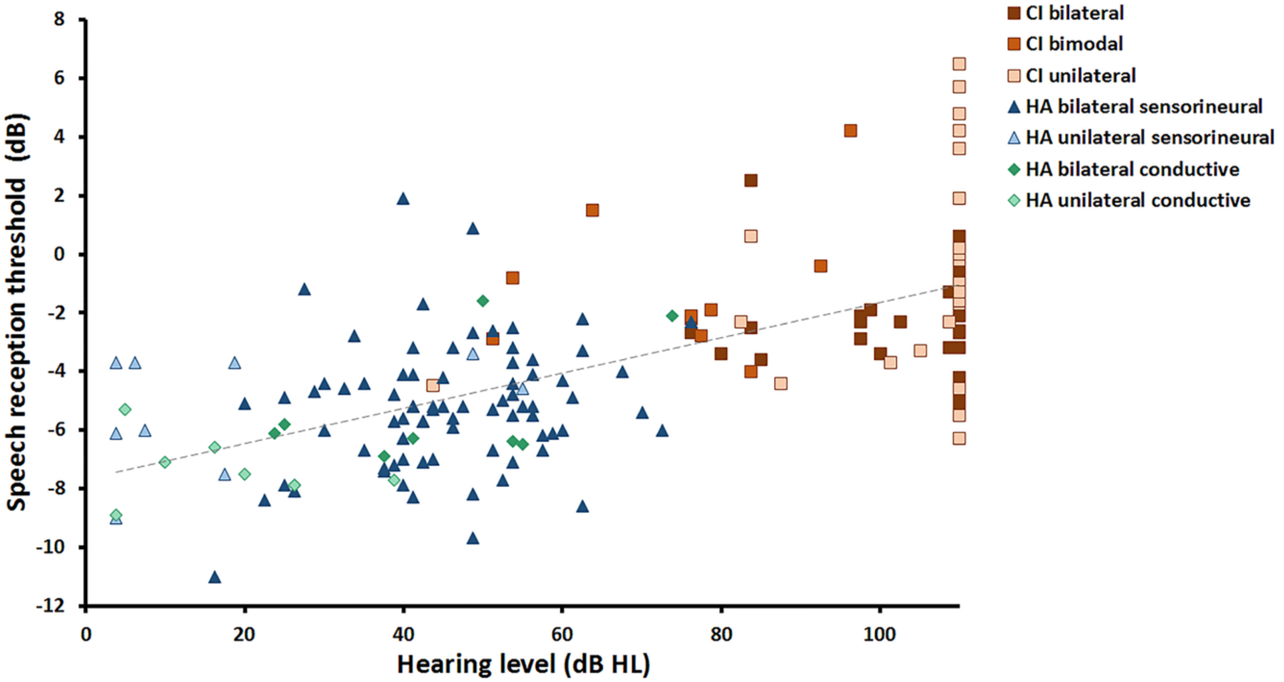

Fig. 4. Pure-tone average (PTA) of the children against speech reception threshold measured with the DIN test. The PTA is the average hearing level of 0.5, 1, 2, and 4 kHz. DIN indicates digits-in-noise.

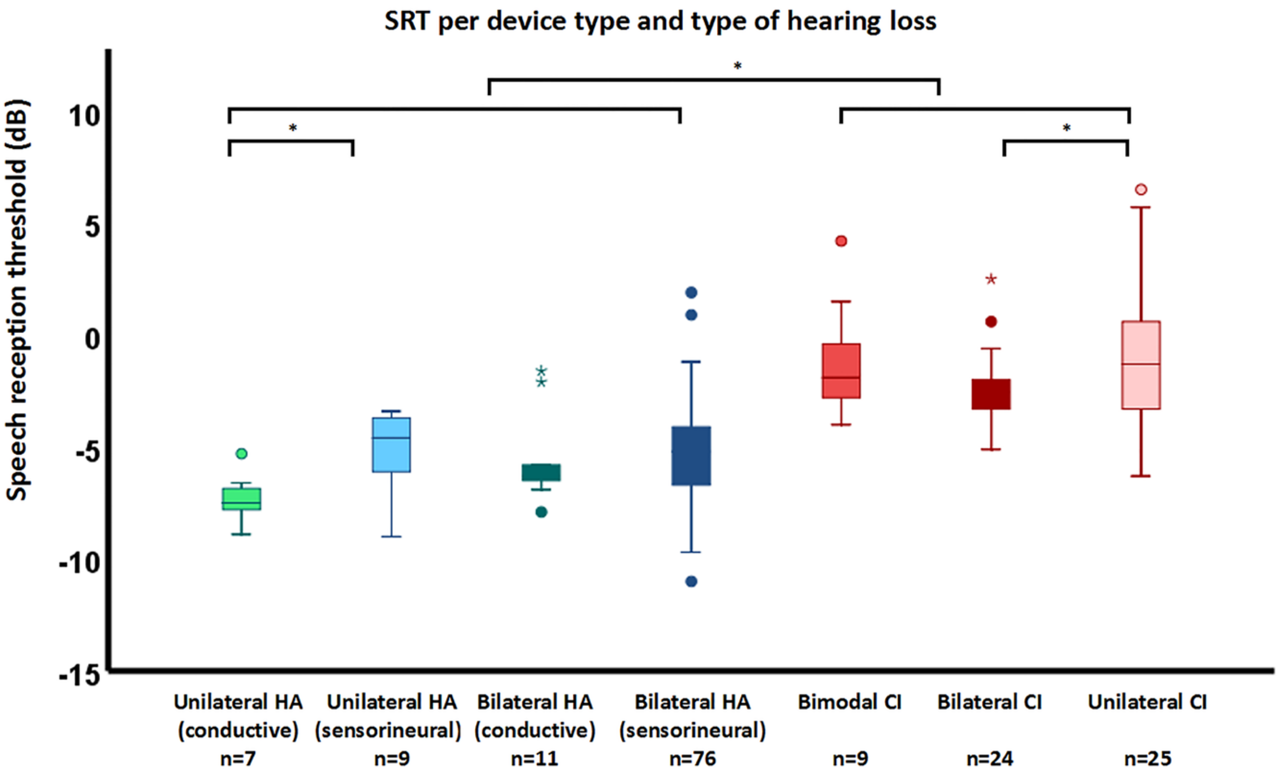

Fig. 5. Speech reception threshold (dB) per device type and type of hearing loss.

possible to assess the speech perception in noise abilities of children from 5 to 18 years old with the DIN test during their clinical appointments. Of note, 28 of the children (15%)—a substantial proportion—could not perform the recommended second list of the test. For these children, the DIN test was either too difficult or they had problems to stay focused to the task. This group performed significantly poorer on the DIN test than the group who could complete both lists. No other differences in group characteristics were found.

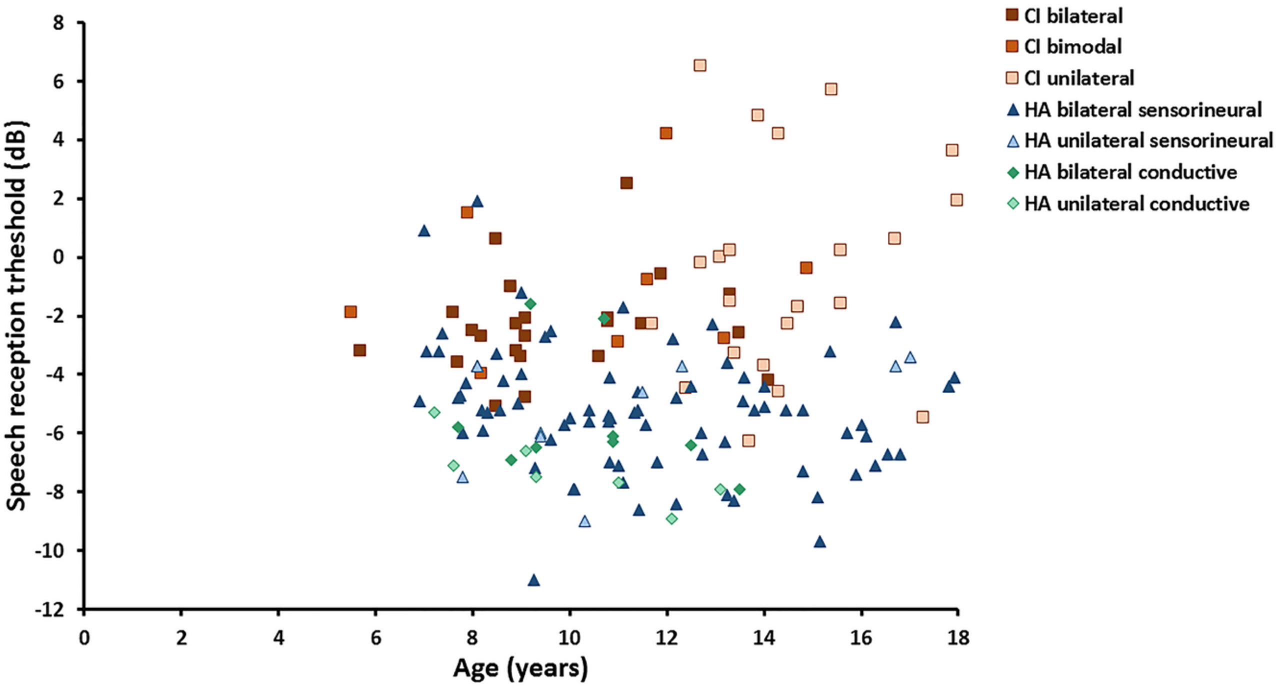

Fig. 6. Speech reception threshold (dB) against age (years).

**TABLE 2. Summary of predictor estimates as a function of SRT**

| | Adjusted $R^2$ | | | | |
|---|---|---|---|---|---|
| | 0.48 | B | *t* | *p* | VIF |
| Chronological age | | 0.014 | 0.203 | 0.839 | 1.092 |
| Amplification device | | 0.448 | 1.698 | 0.092 | 4.626 |
| Hearing level | | 0.029 | 2.531 | $0.012^*$ | 4.557 |
| Speech perception in quiet | | -0.136 | -2.835 | $0.005^*$ | 1.643 |

*Regression coefficients from the multivariate linear regression analysis of four variables correlating with SRT in 156 subjects. $R^2$ = 0.48.*

*B indicates unstandardized regression coefficient; p, significance; SRT, speech reception threshold; t, t statistic; VIF, variance inflation factor.*

## Reliability of the DIN Test for Children With Hearing Loss

The developers of the test (Smits et al. 2013) recommend to assess a training list first, as there might by an improvement of 1.3 dB between the first list and the subsequent lists. Wilson et al. (2005), investigating a digit triplet test, indeed found no difference in SRT for normal-hearing adults between the first and second test list, after the use a practice list. Nevertheless, for adults with hearing loss, even after performing a practice list, still an improvement of 1.1 dB in SNR was found with additional repetitions. Kaandorp et al. (2015) assessed the DIN test in adults using HAs or CIs. They reported an improvement of the SRT (of 0.3 dB) between test lists 1 and 2, despite that the participants had performed a practice list. In our study, the children performed two lists; we found an improvement of 0.4 dB between the first list, serving as a practice list, and the second list. The Bland–Altman plot (shown in Fig. 2) shows that the size of this improvement was small compared with the variability in performance between the first and second lists. This improvement may therefore be considered irrelevant in many situations. Thus, the question arises if a practice list for the DIN test is really needed to assess speech perception in noise in children with hearing loss. Especially with regards to the substantial group of the children in our study for whom it was not possible to perform the second test list, this is an important question to resolve.

Another way to look at this question is to investigate the up-down pattern of the responses of the first and second lists, as shown in Fig. 3. From this analysis, it is clear that a stable SNR was not reached during the first list, while a stable SNR is a requirement for the use of an adaptive procedure to obtain a reliable SRT. Therefore, one could conclude that a second list is needed. In the first part of the second list, the SNR becomes stable. However, from the 10th to 14th triplet on, the SNR deteriorates, possibly due to changes in sustained attention or motivation with increasing number of trials. This counteracts the initial improvement due to learning, and may explain the relatively small difference in SRT we found between the first and second lists compared with other studies. Based on this analysis, it seems that only one list, but with more than 25 triplets, might give the best estimate of the SRT. In that case, the calculation of the SRT needs to include only the triplets for which the SNR had become stable. This line of thought suggests that the number of lists, the number of triplets and the part of the trajectory to determine the average SNR should be optimized when adapting the DIN test for standard pediatric care. Denys et al. (2019) investigated a way of improving the efficiency of the digit triplet test and concluded that the use of variable adaptive step size improved efficiency. Another way to improve the test procedure for future measurements can be to present a short practice list first, provide a break, and then provide a second, test list of digits. From this analysis, it seems that the more severe the hearing loss, the more difficult it is to reach a stable SNR. Assessing speech in noise for individuals with severe hearing loss can be a challenge. Attempts have been made, to adapt speech in noise tests for these individuals; for example, using slower speech using words instead of sentences (van Wieringen & Wouters 2008; Wong & Keung 2013; Zokoll et al. 2013). However, the DIN test we used in the current study has already been adapted to severe hearing losses and the effect of top-down processes is limited. Nevertheless, our data indicate that the learning effect may be stronger for children with a larger hearing loss. The larger hearing loss may also lead to a relatively high initial SNR after the first triplet is correctly heard, resulting in a longer trajectory before a stable SRT is achieved.

## Outcome of the DIN Test for Children With Hearing Loss

In the DIN study of Koopmans et al. (2018), an SRT of −6.7 dB was reported for normal-hearing children of six years old, improving to −10 dB for 18 years old. In our study, we found that children with hearing loss required a higher SNR than do normal-hearing children, on average −1.4 dB for children with CIs and −5.4 dB for children with HAs. Other studies on children with hearing loss (Ching et al. 2011; Nittrouer et al. 2013) also reported a higher SNR than that reported by Koopmans et al. (2018). The variation in SRT between children in our sample is large. For some children, the SNR is comparable with that of normal-hearing children, while others show a much worse performance even in cases of mild or moderate hearing loss. Our multivariate analysis explained only 48% of the variance in SRT, with both aided speech perception in quiet and hearing level as main explaining factors. Remarkably, the difference between device uses only explained a small part of this variability. In a future study, we aim to explore other factors that might lead to these individual differences in SNRs, such as duration of unaided hearing loss, cognitive abilities, and experience with the device. Our results are comparable to those of studies looking into the differences in SRTs between users of HAs and users of CIs. In general, the latter have higher SRTs (Nittrouer et al. 2013; Kaandorp et al. 2015; Ching et al. 2018). We also found an association of degree of hearing loss and the SNR. This was not found in the study of Ching et al. 2018, who assessed this for the children with HAs. The lack of association was possibly due to the smaller range of hearing losses taken into account in that study. Regarding our study, when assessing only the children with bilateral HAs and sensorineural hearing loss, we also did not find a significant correlation between degree of hearing loss and SRT. But in that case, most of the hearing losses are between 40 and 60 dB HL, which is quite a small range.

In our study, we included children with conductive hearing loss wearing conventional HAs. For those wearing bilateral HAs we did not find any differences between the group with sensorineural hearing loss and the group with conductive hearing loss. We had expected to find better SNRs for the latter group, perhaps even comparable to normal-hearing subjects for speech in noise tests based on the Plomp method (Plomp 1986). However, more recent studies indicate that early middle ear disease impacts binaural auditory processing in both humans (Tomlin & Rance 2014; Graydon et al. 2017) and animals (Cook et al. 2002; Tucci et al. (2009). Whitton & Polley (2011) provided a comprehensive review of the effects of conductive hearing loss on hearing in both humans and animals, and concluded that the connection between otitis media-associated degradation of afferent signal quality and subsequent neurological impairment is substantially clearer than generally believed.

Moreover, in a study of Penn et al. (2004) using OME-simulated hearing loss conditions in adults and children, children performed worse on tasks of speech recognition in noise in comparison to adults. Keogh et al. (2010), investigating the effect of mild conductive hearing loss on speech understanding in noise in children, found lower speech perception scores compared to children with normal hearing. As Keogh et al. (2010) did not use an adaptive procedure and speech was presented at 65 dB SPL, these lower scores might have been due to an audibility effect. However, in our current study, we expected the conductive hearing loss to be compensated by the hearing aid, thereby doing away with audibility issues.

The original DIN study of Koopmans et al. (2018) reported an age-dependent SRT for the DIN test for normal-hearing children, in line with other studies investigating speech perception in noise in normal hearing children (Garadat & Litovsky 2007; Van Deun et al. 2010; Reeder et al. 2015; Holder et al. 2016; Mattsson et al. 2018). By contrast, we did not find an effect of age, most likely due to the large variety in the degree of hearing loss which effects the SRT to a much larger extend than age. Koopmans et al. (2018) found a difference of 3.3 dB over an age range of twelve years, which is a smaller difference than the variation in SRT found between the different hearing levels in our population. Another reason we did not find an age effect for the SRT may be that the ages are not evenly distributed over the different categories of hearing loss, although the age difference between the children in the CI group and the children in the HA group is very small. We intend to perform a longitudinal evaluation of the children in our cohort that should make clear whether age, would have an influence on the individual SRT per child. However, we are aware that possible progression of hearing loss might complicate this analysis.

### Strengths and Limitations

A strength of the study is the relatively large sample. Moreover, the inclusion of children with different degrees of hearing loss adds important information to the literature and gives clinicians valuable information about what to expect from speech perception in noise abilities for children with different degrees of hearing loss. Possible limitations of the study are that the test was administered during a clinical follow-up visit, in which the child also performed other audiological tests. Therefore, not every child may have performed to the fullest. Furthermore, we do not have information on how many children were unable to perform the DIN test even for the first list. The study design did not set strict criteria regarding age and degree of hearing loss. A uniform distribution across ages and degree and type of hearing loss was therefore not achieved.

In conclusion, the DIN test can be used to assess speech perception in noise abilities for children with different degrees of hearing loss. We found that children with hearing loss required a higher SNR than normal-hearing children and that the required SNR is larger as the hearing loss increases. For use in standard pediatric audiological care, the procedure used in this study should be improved on several points.

## ACKNOWLEDGMENTS

The authors gratefully thank all team members of the audiological department for collection of the data. They also thank Teun van Immerzeel for his contribution in the data analysis and visualization of the data.

J.L.V. designed the protocol and study, analyzed data and wrote the paper. M.B.A.R. and A.D. performed tests, analyzed data, and provided critical revision of the paper. N.C.H., M.P.v.d.S., and A.G. provided analysis and critical revision of the paper. All authors discussed the results and implications and commented on the manuscript at all stages.

The authors have no conflicts of interest to disclose.

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Received February 7, 2020; accepted October 15, 2020; published online ahead of print February 5, 2021.

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