Developing norms for the Dutch Hearing In Noise Test for children

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List of abbreviations and relevant definitions

CELF-4-NL	Clinical Evaluation of Language Fundamentals: a Dutch norm referenced language test for children aged 5-18.
CVC	Consonant-Vowel-Consonant
dB(A)	(A-weighted) decibels
dBHL	Decibels Hearing Level
DIN	Digits In Noise Test
HINT	Hearing In Noise Test
HU	Hogeschool Utrecht
kHz	Kilohertz
PPVT-3-NL	Peabody Picture Vocabulary Test-3-NL: a norm referenced receptive vocabulary test for children and adults aged 2-99
PTA	Pure Tone Average
SNR	Signal to Noise Ratio
SRT	Speech Reception Threshold
UMCU	University Medical Centre Utrecht

Abstract

Background: In order to develop a Dutch Hearing In Nose Test (HINT) for children, sentences from the adult HINT were selected in a prior study. No norms are available for both children and adults for this newly selected material. Age specific norms are required to compare a child's performance on the HINT with that of normal hearing peers. Normative data enable optimal evaluation of hearing in noise in Dutch children.

Objective: The primary objective of this study was measuring the performance of various age groups of typically developing children and adults on the HINT to generate age specific norms. The secondary objectives were to validate the HINT by comparing the results of typically developing children on the HINT, the Digits In Noise (DIN) test and the Consonant-Vowel-Consonant (CVC) word in noise test, and deriving context factors *j* and *k* from the hearing in noise data. Factors *j* and *k* provide insights in utilization of redundancy in the speech signal.

Method: A total of 29 children and 20 adults participated in this observational, cross-sectional, psychometric study. Participants performed four hearing in noise tests: the HINT, the DIN, the CVC-sense, and CVC-nonsense test. Mean speech reception thresholds per age group are reported, and between-group comparisons are made. Also, means for context factors per age group are reported.

Results: Most hearing in noise performances were significantly affected by age. However, between-group comparisons mostly did not reveal significant differences between consecutive age groups.

Conclusion: The results generate preliminary normative data to compare a child's performance on the HINT with that of normal hearing peers.

Recommendations: Future research should focus on including more children to meet up to the sample size criteria, and on including children who meet the in- and exclusion criteria.

Keywords: hearing in noise test, children, norms, Dutch, context effects

Samenvatting

Achtergrond: Ter ontwikkeling van een Nederlandse *Hearing In Noise Test* (HINT) voor kinderen zijn in een voorgaande studie zinnen geselecteerd uit de volwassen HINT. Voor zowel kinderen als volwassenen is dit nieuwe spraakmateriaal nog niet genormeerd. Leeftijdsspecifieke normen zijn nodig om de score van een kind met de score van normaalhorende leeftijdsgenoten te vergelijken. Normatieve data maken het mogelijk om spraak in ruis verstaan bij kinderen te kunnen evalueren.

Doel: Het primaire doel van deze studie was het vaststellen van gemiddelde scores voor verschillende leeftijdsgroepen van normaal ontwikkelende kinderen en volwassenen op de HINT, om leeftijdsspecifieke normen te ontwikkelen. De secundaire doelen waren het valideren van de HINT, door de resultaten op de HINT, de *Digits In Noise* (DIN) test en de *Consonant-Vowel-Consonant* (CVC) test met elkaar te vergelijken, en het afleiden van de contextfactoren *j* en *k* uit de spraak in ruis tests. Contextfactoren *j* en *k* geven inzicht in het gebruik van redundantie in het spraak signaal.

Methode: In totaal hebben er 29 kinderen en 20 volwassenen meegedaan aan deze observationele, cross-sectionele, psychometrische studie. Participanten hebben aan vier spraak in ruis tests deelgenomen: de HINT, de DIN, de CVC-sense en de CVC-nonsense test. De gemiddelde spraakverstaanbaarheidsdrempels per leeftijdsgroep zijn berekend en er zijn vergelijkingen tussen leeftijdsgroepen gemaakt. Ook zijn de gemiddelde contextfactoren per leeftijdsgroep berekend.

Resultaten: De meeste spraak in ruis resultaten werden significant beïnvloed door leeftijd. Echter, de meeste aaneensluitende leeftijdsgroepen verschilden niet significant van elkaar.

Conclusie: De resultaten geven een eerste indruk van de normatieve data om de score van een kind op de HINT te vergelijken met de scores van normaalhorende leeftijdsgenoten.

Aanbevelingen: Toekomstig onderzoek moet zich richten op het includeren van meer kinderen, zodat er voldaan kan worden aan de benodigde grootte van de onderzoeksgroepen. Ook moeten de in- en exclusiecriteria gehanteerd worden bij het analyseren van de resultaten.

Trefwoorden: spraak in ruis tests, kinderen, normen, Nederlands, context effecten

Introduction

Background noise causes challenging listening conditions in daily life, which hinders understanding speech for certain individuals. A child may be unable to understand the teacher in the classroom when other children are talking in the background for example. An estimated 0.5-1.0% of the general population encounters listening difficulties in noise despite normal audiograms.[1] Therefore, normal pure tone thresholds do not guarantee adequate hearing in everyday situations. Listening difficulties despite normal hearing thresholds are found in young children from the age of 2;9 years old.[1] These children encounter hearing difficulties in class, which limits understanding auditory instruction. Hearing in noise is fundamental for language and reading development and impacts the social and academic development.[2,3] Early detection and subsequent intervention of hearing in noise difficulties is of great importance, since language and reading problems could be prevented.[2]

Since speech consists of highly redundant stimuli, difficulties understanding speech only become apparent under challenging listening conditions.[3] Hearing assessments using pure tones or speech stimuli without background noise do not capture these problems. A Dutch Hearing In Noise Test (HINT) was developed to measure adult speech intelligibility competencies in everyday life sentences.[4] Subjects have to repeat sentences presented in background noise in the HINT. Hearing difficulties despite normal hearing thresholds can be diagnosed with the HINT. However, the Dutch HINT is inappropriate for children, due to their limited language competencies.[5] A prior study selected sentences of the Dutch HINT based on linguistic criteria to develop a child version.[4,6] However, assessing children's hearing in noise competencies under the age of 5 with a HINT, even a child HINT, is invalid due to limited language and memory capacities.[7] Furthermore, twelve-year-olds are expected to approach adult performance, based on a foreign HINT.[4,8] Whether this applies to Dutch twelve-year-olds remains unknown yet. Therefore, the child HINT is initially developed for children aged from 5 up to 12 years old.[7,8] Although the adult HINT is norm-referenced for adults, the mean SRT for adults for the newly selected sentences is unknown. SRTs may differ somewhat across different speech materials and speakers.[9] Therefore, a reference group of adults is included in the current study to adequately compare children's performances with adults' performances, in order to decide whether the HINT norms should be extended to older children.

Test validation is necessary to determine whether the test really reflects the concept it is supposed to denote.[10] However, the lack of a gold standard complicates the child HINT's validation. Correlations between the HINT, the Digits In Noise (DIN) test and the Consonant-Vowel-Consonant word in noise test (CVC-test) are most appropriate.[5,11] In the DIN test, participants have to repeat digits presented in noise. The DIN is norm-referenced for children.[5] Since digits comprise a limited, closed set of stimuli, DIN performance does not fully correspond with hearing in noise performance. Performance on the DIN and the adult HINT is highly correlated, however.[12] In the CVC-test, participants have to repeat meaningful (sense) and meaningless (nonsense) words presented in noise.[11] Phoneme score (number of phonemes correct) and word score (number of words correct) can be derived after test administration. The CVC-test is used in clinical practice, but is not validated or norm-referenced for children.[11] Single words do not utilize syntactic structures. Therefore, CVC-test performance also does not fully correspond with hearing in noise performance.[13,14] However, DIN and CVC-test performance are the best available comparisons for the HINT's validation.

Speech consists of highly redundant stimuli. Factors *j* and *k* express the utilization of linguistic redundancy and provide insights in speech processing.[15,16] Factor *j* describes the relationship between components and the whole, for example between phoneme and word score in a word. For sense stimuli, listeners may predict which phoneme will follow in a word, due to linguistic context. Syntactical, lexical, and semantic context give information about the probability of the following phoneme.[15] However, nonsense stimuli require listeners to hear every phoneme to identify the word correctly. The lacking linguistic context prevents listeners to utilize contextual information. Factor *k* quantifies this relationship between components and its context. Factors *j* and *k* can be derived from speech in noise test performance, which has been done scarcely for children.[17] Due to implications for interventions in children with below-average performance on the HINT, interpreting the HINT performance is useful for speech-language therapists and audiologists.

Objectives

The primary objective is to develop norms of various age groups of typically developing children (i.e. normal language development, no learning or attention difficulties, and no history of middle ear diseases) from 5 up to 12 years old and a reference group of adults from 18 up to 29 years old on the HINT to generate normative data. These normative data allow comparison of a child's performance on a hearing in noise task with that of normal hearing peers and adults.

The secondary objectives are:

- To compare the results of typically developing participants on the HINT, the DIN, and the CVC-test to validate the HINT.
- To derive factors *j* and *k* from the hearing in noise data to gain insights in children's utilization of redundancy in the speech signal. These insights may eventually indicate therapy goals for children with below-average performance on the HINT.

Method

Design

The study comprises an observational, cross-sectional, psychometric design.[18,19]

Participants

The study population consisted of typically developing Dutch children from 5 up to 12 years old and adults from 18 up to 29 years old. Several primary schools in the province of Utrecht, the Netherlands, were contacted to participate in the study. Only one school gave permission for data collection. All children attending this school were invited to participate in the study via posters and the school's newsletter. Additionally, children were recruited via posters in the University Medical Centre Utrecht (UMCU). Adults were recruited via posters in the UMCU and the Hogeschool Utrecht (HU).

Recruitment took place from January 2019 to May 2019. Children were assessed in 8 consecutive age groups from 5 up to 12 years old. Adults were assessed in 2 combined age groups from 18 up to 23 and 24 up to 29 years old, since it remains unknown at what age maximum performance is reached for the new speech material. A sample size of 10 per group was considered appropriate (I. Stegeman, personal communication, November 8th, 2018). This advice corresponds to sample sizes in prior comparable studies.[20,21]

Inclusion criteria were: aged from 5 up to 12 or 18 up to 29 years old; normal hearing in at least one ear, defined as hearing thresholds ≤20 dBHL for frequencies between 250-8000 Hertz; and average performance (within -1 and +1 standard deviation of the mean) on the Peabody Picture Vocabulary Test-3-NL (PPVT-3-NL) and on the Sentence repetition task of the Clinical Evaluation of Language Fundamentals-4-NL (CELF-4-NL).[22,23] Exclusion criteria comprised: atypical development, i.e. better or less than normal language development, attention or learning difficulties; or a history of middle ear diseases, since this influences hearing in noise performance.[24–27]

Data collection

Children participated in two 30-minute sessions which were conducted in a separate room at their primary school, the UMCU or at home. Intervals between the sessions varied from 30 minutes to 14 days. The two sessions were combined into a 60-minute session for adults, which was conducted in a separate room at the HU or at home. In order to prevent attentional bias, short breaks were taken between tests.

Screening

During the first session, three screening tests were performed to determine the participant's eligibility for the study by the researcher. First, the PPVT-3-NL was performed to assess participants' passive vocabulary.[22] Second, pure tone audiometry was conducted to determine hearing thresholds for both ears.[28] Third, the Sentence repetition task of the CELF-4-NL was performed to assess participants' ability to repeat and recall sentences.[23] Both the PPVT-3-NL and the CELF-4-NL have been proven reliable with sufficient structural validity.[22,23]

Hearing in noise tests

During the second session, the hearing in noise tests (HINT, DIN, CVC-test) were performed. Each test was performed twice during the second session to ensure test-retest reliability. The HINT consists of 16 lists, with 13 sentences each.[4,6] The DIN consists of 100 lists, with 24 triplets each.[12] The CVC-test consists of 29 sense and 16 nonsense list, with 24 words per list.[11] The HINT, DIN, and CVC-test were administered in a randomized order between participants to minimize attentional influences on performance. Furthermore, word and sentence lists were randomized over the groups. Randomization was based on Latin squares.[29] The tests were performed monaural using a Sennheiser HD 200 headphone, the researcher's laptop and an ESI-U24 XL sound card.[30] Stimuli were presented to the participant's best ear, based on the Pure Tone Average (PTA) at 1, 2 and 4 kHz.[31] When the PTA was identical for both ears, stimuli were presented to the right ear. The volume of all noise stimuli was identical for all participants (laptop setting volume: 65 dBA). The Speech Reception Threshold (SRT; the Signal-to-Noise Ratio (dB) at which 50% of the stimuli is repeated entirely correctly) was determined with an up-down procedure, in which the speech volume was adapted according to correct or incorrect responses.[4] The spectrum of the masking noise was matched to the long-term average spectrum of the speech stimuli. At the start of the session, a certificate was presented to children at which they could place stickers during short breaks between tests. Adults also had short breaks between tests. If the researcher observed attention loss, an extra break was taken to motivate the participant.

Study variables

The dependent variables of the study comprised the SRT on the HINT, DIN, and CVC-test, and factors *j* and *k*, which were all derived from the hearing in noise tests. The SRT was determined with both an up-down adaptive procedure and an estimated fit based on the test results (see Appendix 1 for the fit).[4] Factors *j* and *k* were calculated according to the functions developed by Boothroyd & Nittrouer.[15] Factor *k* was not derived for the DIN versus other tests, since the DIN stimuli do not use any syntactic structures. Calculating factor *k* for the DIN was therefore considered useless. Furthermore, the word, phoneme, and digit scores were computed, based on correctly repeated components in the hearing in noise tests. For example, the word score was computed for the HINT, based on correctly repeated words in the sentences. The independent variable was age.

Data analysis

All statistical analyses were performed with IBM SPSS Statistics 23. Unless indicated otherwise, analyses were performed with significance level 0.05. Dependent t-tests and Wilcoxon Matched-Pairs tests were used to assess differences between test and retest results for the hearing in noise tests. Furthermore, Kruskal-Wallis tests were used to assess whether age affected the results. When age affected the results significantly, Mann-Whitney U tests were used to compare between age groups for the adaptive SRTs. Spearman's correlation was used to assess correlations between the hearing in noise tests.

Ethical considerations

The study was approved by the Medical Ethical Committee of the UMCU (No. 18-893/C). The committee declared that the Medical Research Involving Human Subjects Acts does not apply to this study. Informed consent was given by adults or both parents (or caregivers) of children before participation in the study.

Results

Participants

Of the 53 cases who were contacted to participate in the study, 49 provided informed consent. A total of 29 children and 20 adults participated in the study. All participants completed the experiments. The participants' baseline characteristics and screening results are shown in Table 1. Participants who did not meet the inclusion criteria, were included in the current results nonetheless, since this is an interim report of the findings and sample sizes are limited so far. In the future, the in- and exclusion criteria will be applied to the participants in order to develop reliable norms.*

Hearing in noise tests

Data were normally distributed for the HINT test, *D* (49) = 0.08, *p* = .200, and retest, *D* (49) = 0.12, *p* = .097, condition. The test (*M* = -2.36, *SE* = 0.24) and retest (*M* = -2.73, *SE* = 0.24) data did not differ significantly, *t* (48) = 1.50, *p* = 0.140.

Date were non-normally distributed for the DIN test, *D* (49) = 0.14, *p* = .019, but normally for the DIN retest, *D* (49) = 0.08, *p* = .200. The DIN test (*M* = -7.25, *SD* = 1.72) and retest (*M* = -7.69, *SD* = 1.48) data differed significantly, *Z* = -2.703, *p* = .007.

CVC-sense data were normally distributed for the test, *D* (49) = 0.09, *p* = .200, and retest condition, *D* (49) = 0.09, *p* = .200. The CVC-sense test (*M* = -3.38, *SE* = 0.32) and retest (*M* = -3.95, *SE* = 0.25) did not differ significantly, *t* (48) = 1.61, *p* = 0.115.

CVC-nonsense data were normally distributed for the test, *D* (49) = 0.11, *p* = .178, and retest condition, *D* (49) = 0.07, *p* = .200. The CVC-nonsense test (*M* = 0.44, *SE* = 0.41) and retest data (*M* = -0.66, *SE* = 0.38) differed significantly, *t* (48) = 3.43, *p* = .001.

Data could not be pooled for the DIN and CVC-nonsense test, since learning effects were found. For the sake of the analogy in the analyses, it was decided not to pool the HINT and CVC-sense data either. Therefore, only the retest data are analysed from now on.

The SRT values versus age are presented in Figure 1 for the HINT, DIN, CVC-sense, and CVC-nonsense. Furthermore, the adult speech recognition functions for the HINT, CVC-sense, and CVC-nonsense are presented in Figure 2. The sample sizes of children were too limited to create speech recognition functions.

* N.B.: This decision was made based on the fact that this report concerns a master thesis. When the in- and exclusion criteria were applied to the participants, the results were too limited to write a proper analysis for the master thesis. Therefore, it was decided to include all participants in the current report. In the future, the in- and exclusion criteria will be applied before publishing the final results.

HINT

Adaptive SRT results for the HINT were significantly affected by age, *H* (8) = 34.47, *p* < .001. A Bonferroni correction was applied for the between-group comparisons; thus, effects are reported at a 0.0167 significance level. Between-group comparisons revealed no significant difference between adaptive SRTs for 6-year-olds and 8-year-olds (*U* = 7.000, *z* = -2.043, *p* = .051), 8-year-olds and 11-year-olds (*U* = 6.000, *z* = -0.791, *p* = .548), and 11-year-olds and 18-23-year-olds (*U* = 5.000, *z* = -1.726, *p* = .112).

The fitted SRT (*H* (8) = 31.23, *p* < .001) and the word score (*H* (8) = 26.40, *p* < .001) were significantly affected by age.

The mean adaptive SRT, fitted SRT, and word scores per age group are presented in Table 2.

DIN

Adaptive SRT results for the DIN were significantly affected by age, *H* (8) = 35.91, *p* < .001. Between-group analyses indicated no significant differences between 6-year-olds and 8-year-olds (*U* = 18.000, *z* = -0.429, *p* = .731), and 8-year-olds and 11-year-olds (*U* = 4.500, *z* = -1.167, *p* =.262). However, adaptive SRTs for 11-year-olds differed significantly from adaptive SRTs for 18-23-year-olds (*U* = 1.000, *z* = -2.393, *p* = .014).

The fitted SRT, *H* (8) = 35.89, *p* < 0.001, and the digit score, *H* (8) = 36.30, *p* < .001, were significantly affected by age.

The mean adaptive SRT, fitted SRT, and digit score for all age groups are presented in Table 3.

CVC-sense

The adaptive SRT results for the CVC-sense test were not significantly affected by age, *H* (8) = 13.52, *p* = .095. The fitted SRT was not significantly affected by age either, *H* (8) = 13.95, *p* = .083. However, the phoneme score was significantly affected by age, *H* (8) = 15.64, *p* = .048.

The mean adaptive SRT, fitted SRT, and phoneme score for all age groups are presented in Table 4.

CVC-nonsense

The adaptive SRT for the CVC-nonsense test was significantly affected by age, *H* (8) = 23.45, *p* = .003. Between-group analyses indicated no significant difference between 6-year-olds and 8-year-olds (*U* = 14.500, *z* = -0.930, *p* = .366), 8-year-olds and 11-year-olds (*U* = 5.000, *z* = -1.033, *p* = .381), and 11-year-olds an 18-23-year-olds (*U* = 5.500, *z* = -1.610, *p* = .112).

The fitted SRT was significantly affected by age, *H* (8) = 21.97, *p* = .005. However, the phoneme score was not significantly affected by age, *H* (8) = 14.18, *p* = .077.

The mean adaptive SRT, fitted SRT, and phoneme score per age group are presented in Table 5.

Correlations

Correlations between the HINT, DIN, CVC-sense, and CVC-nonsense were calculated. Significant correlations were found between the HINT and the DIN (*Rs* = .67, *p* < .001), the HINT and the CVC-sense test (*Rs* = .41, *p* = .004), and the HINT and CVC-nonsense test (*Rs* = .53, *p* < .001). Scatter plots for the HINT results versus DIN, CVC-sense, and CVC-nonsense results are presented in Figure 3. All correlations are reported in Table 6.

<u>Factors *j* and *k*</u>

Factors *j* and *k* were derived from the hearing in noise data. Factor *j* was not significantly affected by age for the HINT, *H* (8) = 4.83, *p* = .776, the DIN, *H* (8) = 7.57, *p* = .476, the CVC-sense, *H* (8) = 10.97, *p* = .204, and the CVC-nonsense, *H* (8) = 3.70, *p* = .883. Mean factors *j* for all age groups are presented in Table 7.

Factor *k* was not significantly affected by age for the CVC-sense versus the HINT, *H* (8) = 11.10, *p* = .196, the CVC-nonsense versus the HINT, *H* (8) = 3.98, *p* = .859, and the CVC-nonsense versus the CVC-sense, *H* (8) = 4.54, *p* = .805. Mean factors *k* per test combination for all age groups are presented in Table 8.

Discussion

The objective of the current study was to generate norms for the Dutch HINT for children aged 5 up to 12 years old. Participants were assessed with four hearing in noise tests (the HINT, the DIN, the CVC-sense, and CVC-nonsense test) in order to generate age specific norms and to validate the HINT. Mean SRT levels for all age groups were given for all hearing in noise tests. Hearing in noise results for the HINT, DIN, and CVC-nonsense test were significantly affected by age. However, most performance levels did not differ significantly between consecutive groups. Correlations between the HINT and the other hearing in noise tests were low or moderate. Furthermore, factors *j* and *k* were computed for all age groups on the hearing in noise data in order to provide insights in children's utilization of redundancy in the speech signal. Factor *j* and *k* were not affected by age, which implicates no better use of the redundancy in the speech signal in adults than in children for the current speech material.

The current study expands the findings of a prior study in the development of the Dutch HINT for children, in which sentences were selected.[6] Defining children's SRTs for Dutch sentences in noise has not been done in the past. The HINT results are however not completely in agreement with prior studies concerning foreign HINTs for children. A previous study reported the highest thresholds in the youngest age group, while the current study did not consequently find the highest thresholds with the youngest children.[20] However, the current study did report children's SRTs on the DIN which are comparable to prior findings.[5] The reported SRTs for adults in the current study are somewhat higher than in prior research into the Dutch HINT for adults.[32] Furthermore, significant differences between all age groups were reported in a prior study.[33] However, far from all between-group comparisons differed significantly in the current study. These contradictions might be due to the small sample sizes and the fact that participants did not fully meet the in- and exclusion criteria in the current study.

The low and moderate correlations between the HINT and the other hearing in noise tests implicate that the tests measure other constructs. This may be explained by the fact that the stimuli in the CVC-sense, CVC-nonsense, and DIN do not use syntactical structures (i.e. they are words or digits), while the HINT sentences do use syntactical structures. The low and moderate correlations underline the need for a Dutch child HINT, since HINT results cannot be predicted with other available hearing in noise tests.

Furthermore, the current study adds to the knowledge of the utilization of redundancy in the speech signal in children by deriving context factors *j* and *k* from the hearing in noise data. Children did not make less use of the context than adults in the current study. Context factors have been studied extensively in adults, but scarcely in children.[15–17,34–36] Knowledge about the use of context in children's speech processing can help interpreting the hearing in noise data. When a child shows below-average performance on the HINT, factors *j* and *k* can indicate suboptimal use of the linguistic context. Eventually, this may indicate which intervention is appropriate.

Some limitations of the current study are worth noting when interpreting the findings. First, the results presented are very preliminary. Because of difficulties in finding participating schools, the start of the data collection was delayed, and data collection is not finished yet. Therefore, only 29 children are included until now. Sample size calculation indicated a sample of 80 children, however. The reported results may therefore be unreliable. The sample sizes may be too limited to detect any differences between age groups, which were expected based on foreign HINTs for children.[13,20,33]

Second, included children did not meet all in- and exclusion criteria. Some children showed above-average performance on the PPVT-3-NL or the CELF-4-NL. Furthermore, some children had pure tone thresholds above 20 dBHL. Parents also reported a history of middle ear diseases or attention and learning difficulties in some children. Atypical development, i.e. better or less than normal language development, attention or learning difficulties, or increased hearing levels, is expected to negatively influence hearing in noise results.[24–27] Due to limited interest from parents to have children participate in the study, it was decided to include all children of whom parents signed informed consent. However, the current findings are expected to be negatively affected because of this.

Future research should focus on including more children in order to comply with the sample size criteria. This is expected to generate more reliable results. Only then, the findings can be used as norms in clinical practice to compare a child's performance with that of normal hearing peers. Future research should also focus on including children with a typical development, since this enables comparisons between performance of a child with hearing in noise problems with typically developing peers.

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Tables

Table 1

Baseline characteristics of the participants.

AGE (YEAR;MONTHS)	n	*% MALE*	*PPVT-3-NL (SD; RANGE)**	*CELF-4-NL (SD; RANGE)***
CHILDREN				
5;0-5;11	3	100%	116.3 (16.6; 99-132)	10.3 (1.2; 9-11)
6;0-6;11	7	71.4%	114.3 (10.7; 93-126)	11.1 (1.5; 9-13)
7;0-7;11	5	60%	107.8 (13.1; 86-119)	11.0 (2.6; 8-14)
8;0-8;11	6	66.7%	108.2 (10.0; 98-125)	11.3 (1.8; 8-13)
9;0-9;11	4	0%	111.3 (16.8; 98-133)	12.0 (3.6; 7-15)
10;0-10;11	1	0%	119***	14***
11;0-11;11	3	66.7%	116.7 (11.6; 109-130)	12.0 (1.0; 11-13)
12;0-12;11	0	-	-	-
ADULTS				
18;0-23;11	10	11.1%	107.4 (10.0; 94-123)	11.7 (2.2; 9-15)
24;0-29;11	10	50%	105.5 (12.3; 75-121)	11.6 (2.2; 9-15)

*PPVT-3-NL: Peabody Picture Vocabulary Test-3-NL; SD: Standard Deviation. Performance within -1 and +1 SD of the mean ranges from 85-115.

**CELF-4-NL: Clinical Evaluation of Language Fundamentals-4-NL; SD: Standard Deviation. Performance within -1 and +1 SD of the mean ranges from 7-13.

***Since this group consists of only 1 participant, no standard deviation and range are reported.

Table 2

*Mean adaptive and fitted SRTs and word scores for the HINT per age group.**

AGE (YEAR;MONTHS)	ADAPTIVE SRT (SD)*	FITTED SRT (SD)*	WORD SCORE (SD)*
CHILDREN			
5;0-5;11	-1.7 (1.0)	-1.5 (1.0)	-3.0 (1.0)
6;0-6;11	-0.9 (1.2)	-0.8 (1.5)	-2.8 (0.8)
7;0-7;11	-2.1 (1.1)	-1.9 (1.2)	-3.8 (1.4)
8;0-8;11	-2.3 (0.9)	-2.3 (1.0)	-4.6 (0.6)
9;0-9;11	-1.7 (0.7)	-1.8 (0.8)	-4.0 (0.8)
10;0-10;11	1.0**	0.8**	-2.7**
11;0-11;11	-2.5 (1.6)	-2.7 (2.3)	-4.4 (2.0)
12;0-12;11	-	-	-
ADULTS			
18;0-23;11	-4.1 (0.8)	-4.0 (0.8)	-6.2 (0.8)
24;0-29;11	-4.3 (0.8)	-4.1 (1.0)	-5.9 (0.7)

*SRT: Speech Reception Threshold; HINT: Hearing In Noise Test; SD: Standard Deviation.

**Since this group consists of only 1 participant, no standard deviation and range are reported.

Table 3

*Mean adaptive and fitted SRTs and digit scores for the DIN test per age group.**

AGE (YEAR;MONTHS)	ADAPTIVE SRT (SD)*	FITTED SRT (SD)*	DIGIT SCORE (SD)*
CHILDREN			
5;0-5;11	-5.3 (1.0)	-5.1 (1.0)	-6.1 (0.8)
6;0-6;11	-6.4 (1.3)	-6.1 (1.6)	-8.1 (1.5)
7;0-7;11	-7.0 (1.0)	-6.8 (1.4)	-9.3 (0.7)
8;0-8;11	-7.0 (0.3)	-6.9 (0.5)	-8.8 (1.1)
9;0-9;11	-7.6 (0.8)	-7.5 (0.9)	-9.5 (0.4)
10;0-10;11	-9.3**	-9.7**	-11.3**
11;0-11;11	-6.6 (1.1)	-6.6 (0.7)	-9.5 (1.1)
12;0-12;11	-	-	-
ADULTS			
18;0-23;11	-9.2 (0.7)	-9.2 (0.8)	-11.5 (0.6)
24;0-29;11	-8.8 (0.8)	-8.7 (0.8)	-10.8 (0.9)

*SRT: Speech Reception Threshold; DIN: Digits In Noise test; SD: Standard Deviation.

**Since this group consists of only 1 participant, no standard deviation and range are reported.

Table 4

*Mean adaptive and fitted SRTs and phoneme scores for the CVC-sense test per age group.**

AGE (YEAR;MONTHS)	ADAPTIVE SRT (SD)*	FITTED SRT (SD)*	PHONEME SCORE (SD)*
CHILDREN			
5;0-5;11	-2.8 (0.9)	-2.7 (1.2)	-5.5 (2.8)
6;0-6;11	-2.3 (2.1)	-2.0 (2.3)	-5.5 (2.4)
7;0-7;11	-3.2 (1.8)	-3.1 (2.0)	-6.1 (1.3)
8;0-8;11	-4.3 (1.3)	-3.9 (1.1)	-6.9 (1.0)
9;0-9;11	-4.0 (1.7)	-3.9 (1.7)	-7.7 (2.1)
10;0-10;11	-3.4**	-3.3**	-6.0**
11;0-11;11	-3.5 (1.3)	-3.2 (1.1)	-7.3 (1.1)
12;0-12;11	-	-	-
ADULTS			
18;0-23;11	-5.0 (1.5)	-5.0 (1.6)	-8.9 (1.9)
24;0-29;11	-4.8 (1.4)	-4.7 (1.4)	-7.6 (1.1)

*SRT: Speech Reception Threshold; CVC-sense: Consonant-Vowel-Consonant sense words test; SD: Standard Deviation.

**Since this group consists of only 1 participant, no standard deviation and range are reported.

Table 5

*Mean adaptive and fitted SRTs and phoneme scores for the CVC-nonsense test per age group.**

AGE (YEAR; MONTHS)	ADAPTIVE SRT (SD)*	FITTED SRT (SD)*	PHONEME SCORE (SD)*
CHILDREN			
5;0-5;11	0.6 (3.6)	0.6 (3.4)	-3.2 (1.6)
6;0-6;11	0.8 (1.2)	0.8 (1.2)	-6.2 (3.2)
7;0-7;11	1.3 (1.9)	3.3 (2.3)	-5.6 (1.9)
8;0-8;11	1.3 (2.5)	1.5 (3.1)	-4.1 (3.9)
9;0-9;11	0.5 (2.5)	1.0 (2.6)	-4.5 (3.2)
10;0-10;11	-2.4**	-2.5**	-5.2**
11;0-11;11	-0.5 (2.2)	-2.2 (3.6)	-9.9 (7.1)
12;0-12;11	-	-	-
ADULTS			
18;0-23;11	-3.6 (1.8)	-3.1 (2.4)	-8.4 (2.0)
24;0-29;11	-1.6 (2.0)	-1.5 (2.3)	-6.3 (2.3)

*SRT: Speech Reception Threshold; CVC-nonsense: Consonant-Vowel-Consonant nonsense words test; SD: Standard Deviation.

**Since this group consists of only 1 participant, no standard deviation and range are reported.

Table 6

Spearman's correlation coefficient for all hearing in noise test combinations.

	HINT*	DIN*	CVC-SENSE*	CVC-NONSENSE*
HINT				
DIN	.672**			
CVC-SENSE	.406**	.549**		
CVC-NONSENSE	.529**	.650**	.376**	

*HINT: Hearing In Noise Test; DIN: Digits In Noise test; CVC-sense: Consonant-Vowel-Consonant sense words test; CVC-nonsense: Consonant-Vowel-Consonant nonsense words test.
**Correlation is significant at the 0.01 level (2-tailed).

Table 7

Mean factor j scores per age group per hearing in noise test.

AGE (YEAR;MONTHS)	HINT (SD)*	DIN (SD)*	CVC-SENSE (SD)*	CVC-NONSENSE (SD)*
CHILDREN				
5;0-5;11	3.4 (2.5)	2.4 (0.9)	1.9 (0.4)	2.9 (0.6)
6;0-6;11	2.7 (0.8)	2.3 (0.6)	2.5 (0.6)	3.0 (0.6)
7;0-7;11	2.6 (0.6)	2.9 (1.2)	2.3 (0.3)	3.0 (0.2)
8;0-8;11	2.9 (1.0)	3.1 (1.5)	2.1 (0.5)	3.1 (0.8)
9;0-9;11	3.3 (1.5)	2.7 (0.8)	2.3 (0.4)	3.1 (0.5)
10;0-10;11	3.9**	2.2**	2.5**	3.0**
11;0-11;11	5.1 (5.6)	3.3 (0.7)	2.8 (0.4)	2.9 (0.7)
12;0-12;11	-	-	-	-
ADULTS				
18;0-23;11	3.4 (1.1)	4.0 (3.8)	2.6 (0.3)	2.9 (0.5)
24;0-29;11	2.6 (0.7)	3.3 (1.0)	2.3 (0.7)	2.7 (0.4)

*HINT: Hearing In Noise Test; SD: Standard Deviation; DIN: Digits In Noise test; CVC-sense: Consonant-Vowel-Consonant sense words test; CVC-nonsense: Consonant-Vowel-Consonant nonsense words test.
**Since this group consists of only 1 participant, no standard deviation and range are reported.

Table 8

Mean factor k scores per age group per test combination.

AGE (YEAR;MONTHS)	CVC-SENSE VS. HINT (SD)*	CVC-NONSENSE VS. HINT (SD)*	CVC-NONSENSE VS. CVC-SENSE (SD)*
CHILDREN			
5;0-5;11	1.6 (0.6)	14.6 (23.0)	7.3 (4.2)
6;0-6;11	2.4 (1.3)	3.3 (1.1)	3.5 (1.4)
7;0-7;11	1.5 (0.4)	2.9 (1.1)	5.7 (2.2)
8;0-8;11	1.4 (0.6)	12.8 (15.2)	11.2 (11.6)
9;0-9;11	1.4 (0.7)	8.5 (8.5)	5.6 (4.1)
10;0-10;11	1.2**	1.4**	3.1**
11;0-11;11	2.0 (1.2)	3.2 (2.3)	3.7 (1.9)
12;0-12;11	-	-	-
ADULTS			
18;0-23;11	2.9 (2.9)	3.7 (2.9)	3.6 (2.0)
24;0-29;11	4.7 (7.4)	6.9 (8.1)	6.5 (7.7)

*CVC-sense: Consonant-Vowel-Consonant sense words test; VS.: versus; HINT: Hearing In Noise Test; SD: Standard Deviation; CVC-nonsense: Consonant-Vowel-Consonant nonsense words test.

**Since this group consists of only 1 participant, no standard deviation and range are reported.

Figures

Figure 1

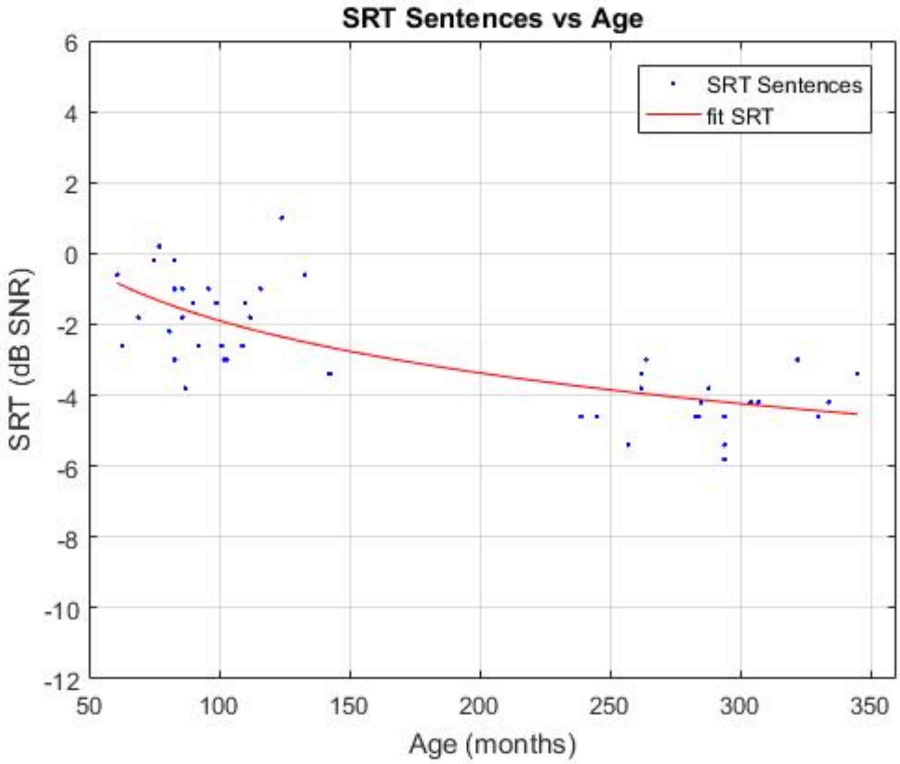

Figure 1a. Speech Reception Threshold (SRT) for the Hearing In Noise Test (HINT) sentences versus age in months

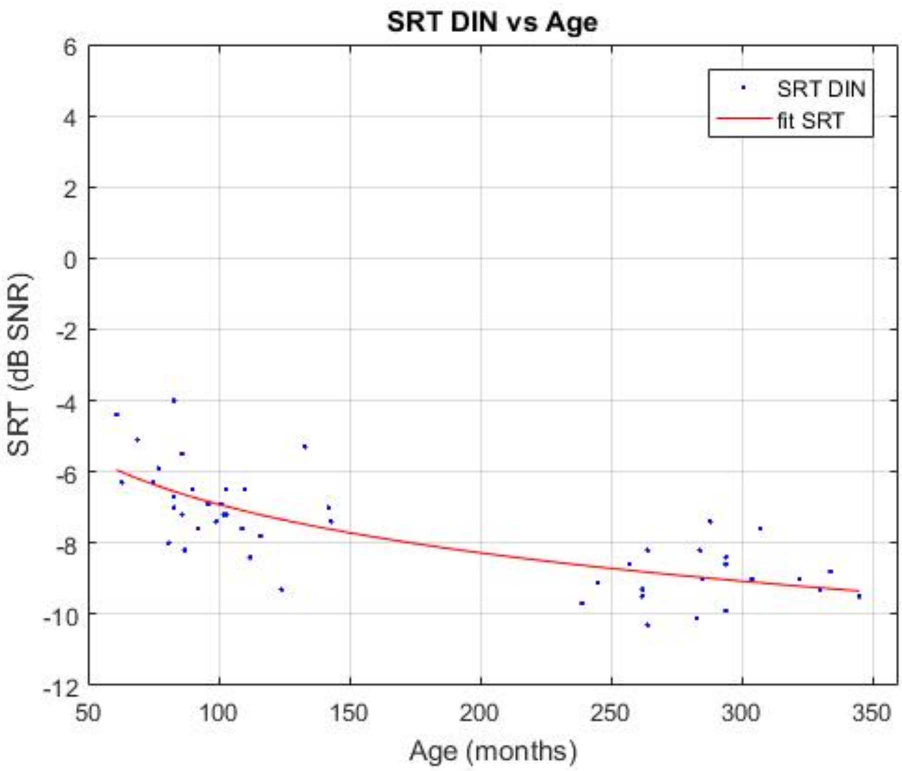

Figure 1b. Speech Reception Threshold (SRT) for the Digits In Noise (DIN) test versus age in months.

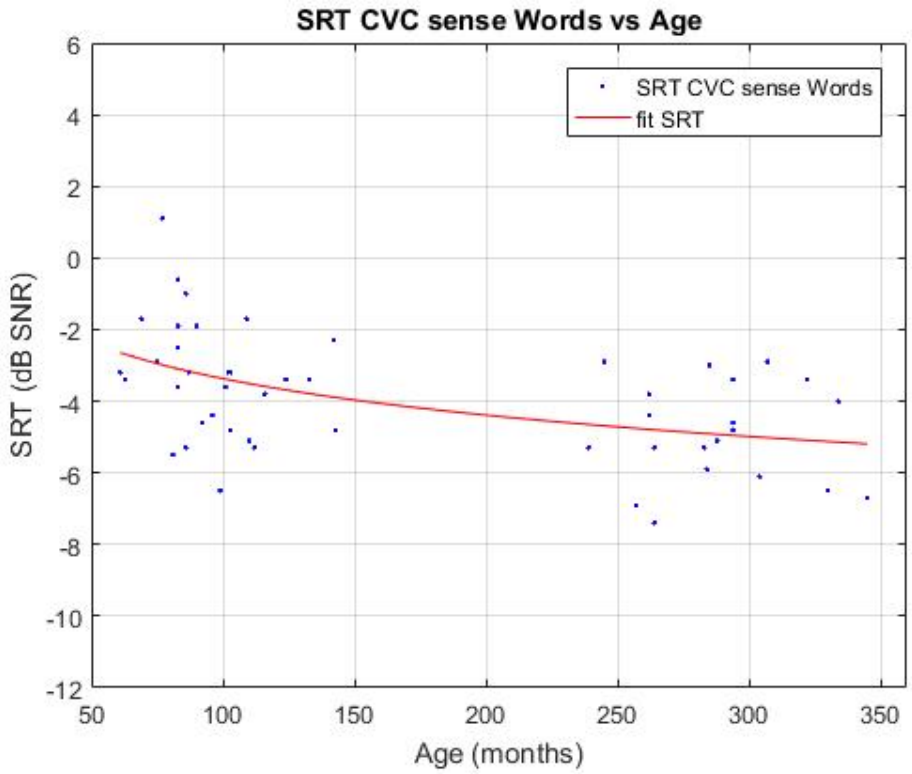

Figure 1c. Speech Reception Threshold (SRT) for the Consonant-Vowel-Consonant (CVC) sense words test versus age in months.

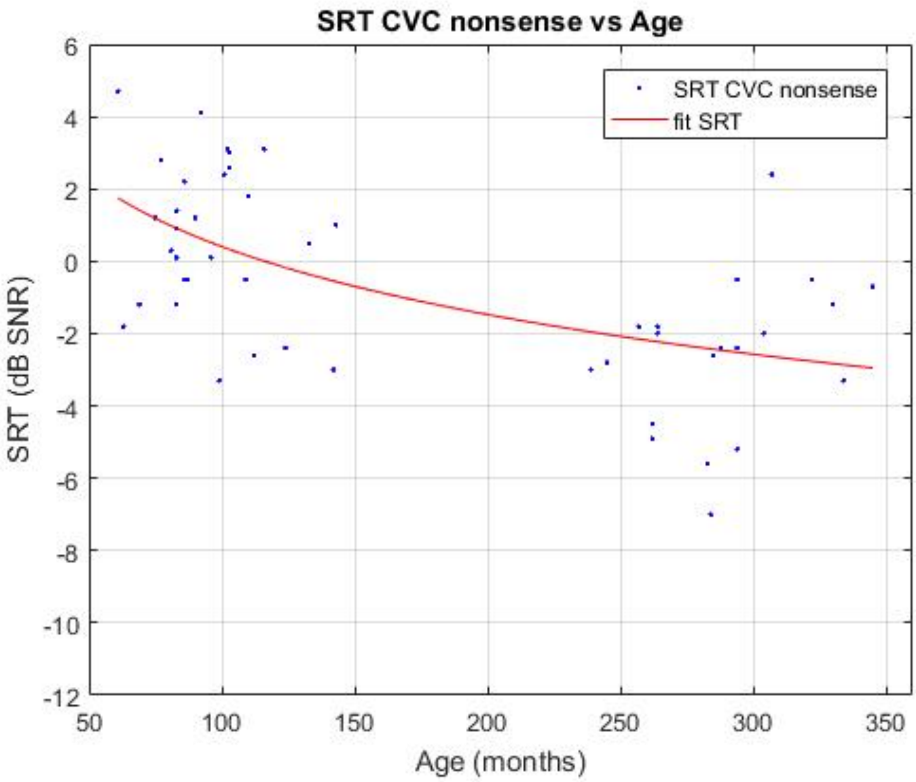

Figure 1d. Speech Reception Threshold (SRT) for the Consonant-Vowel-Consonant (CVC) nonsense words test versus age in months.

Figure 2

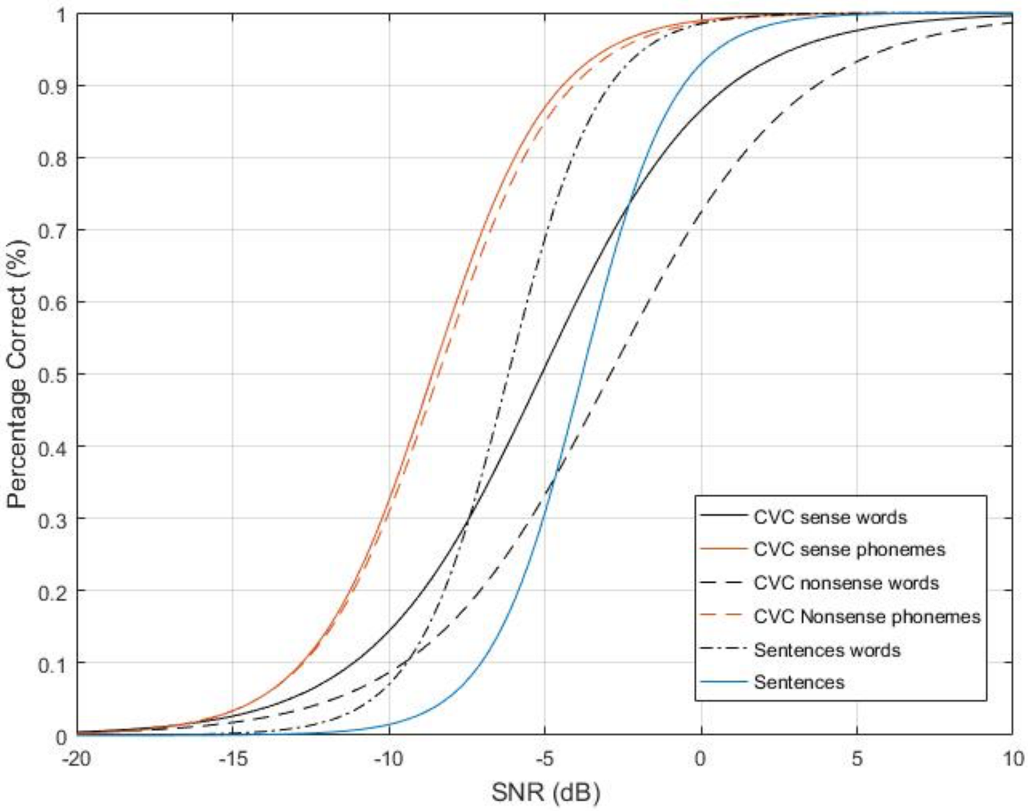

Figure 2. The adult speech recognition functions for the Hearing In Noise Test (HINT) sentences, HINT words in sentences, Consonant-Vowel-Consonant (CVC) nonsense phonemes, CVC-nonsense words, CVC-sense phonemes, and CVC-sense words.

Figure 3

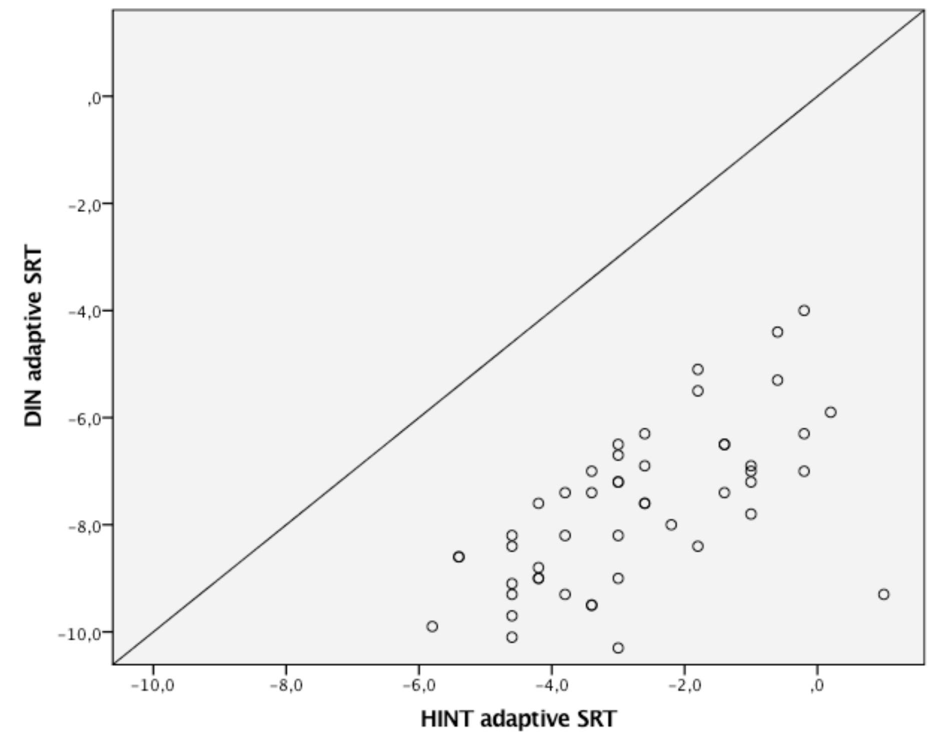

Figure 3a. Scatterplot for the Hearing In Noise Test (HINT) adaptive Speech Reception Thresholds (SRT) versus the Digits In Noise (DIN) adaptive SRTs.

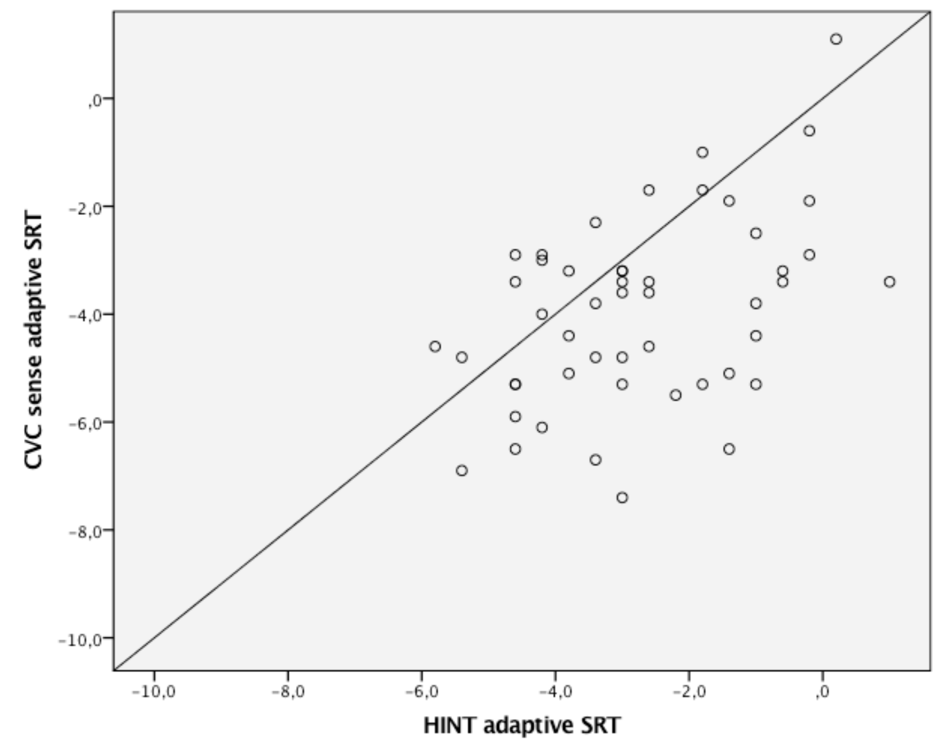

Figure 3b. Scatterplot for the Hearing In Noise Test (HINT) adaptive Speech Reception Thresholds (SRT) versus the Consonant-Vowel-Consonant (CVC) sense words test adaptive SRTs.

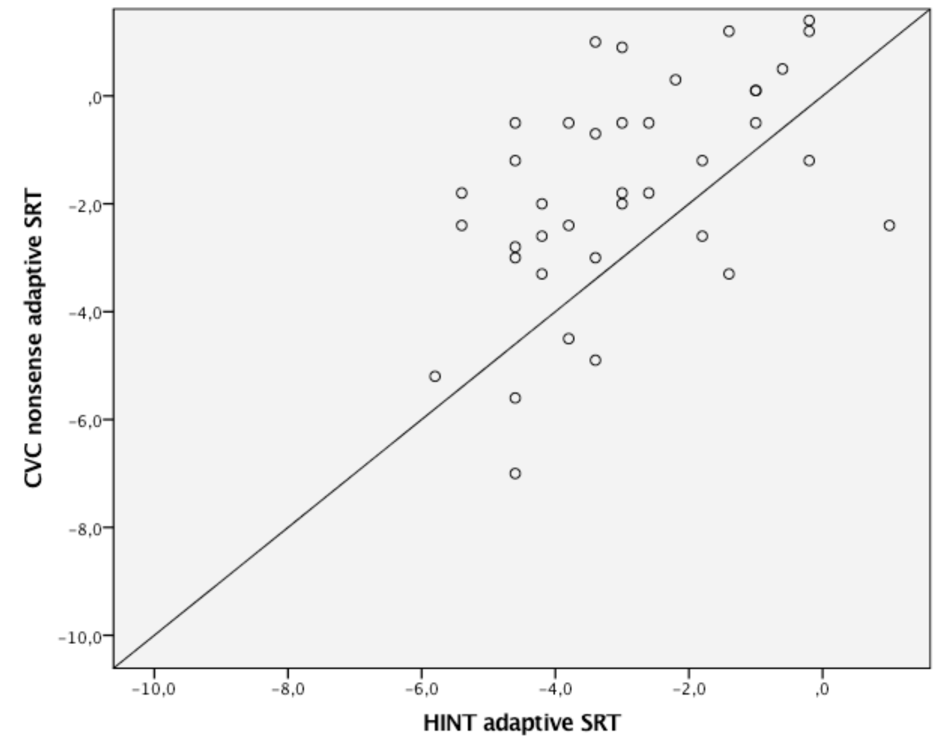

Figure 3c. Scatterplot for the Hearing In Noise Test (HINT) adaptive Speech Reception Thresholds (SRT) versus Consonant-Vowel-Consonant (CVC) nonsense words test adaptive SRTs.

Appendices

Appendix 1

The fitted SRTs were calculated with the following function:

$$SRT = a * \log(Age\ in\ months) + b$$

The coefficients and R^2 for each hearing in noise test are reported in Table 1.

Table 1

Coefficients and R^2 for the fitted SRT function for each hearing in noise test.

	a	b	R^2
HINT*	-2.1326	7.9293	.5670
DIN*	-1.9612	2.1173	.5915
CVC-sense*	-1.4702	3.4021	.2430
CVC-nonsense*	-2.7107	12.8903	.3494

*HINT: Hearing In Noise Test; DIN: Digits In Noise test; CVC-sense: Consonant-Vowel-Consonant sense words test; CVC-nonsense: Consonant-Vowel-Consonant nonsense words test.