# Speech audiometry test with picture-related sentence lists in Modern Greek for partially hearing children

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**Abstract**

**Objective**: The aim of this study was to develop Greek Sentence Based Speech Audiometry Test in quiet test for Hearing Impaired (HI) children (G-SEBSAT).
**Methods**: Seventy-six children were recruited following approval by the local ethics committee and after obtaining informed consent from their parents. The collection of vocabulary was based on showing pictures selected from popular reading materials in Greek to hearing impaired HI children. A grammatical content analysis was carried out to determine the average syntactic and morphological structures of the sentences used by the HI children. Ten picture related sentence lists were developed based on the vocabulary and the grammatical analysis, and recorded by a male native speaker of standard Modern Greek. These were presented to both normal hearing (NH) and HI children, and the average speech response threshold (SRT) as well as the slope of the SRT curve at the SRT level of 50% correct responses ($S_{50}$) were recorded in both groups. Sentence lists were validated with respect to the variability of their difficulty within each group, as well the test-retest variability of the respective SRT scores.
**Results**: The average speech response threshold (SRT) across all lists for HI children was 65.27 dB and the slope of the SRT curve at the SRT level of 50% correct responses was 3.11%/dB. The corresponding results across all lists for NH children were 17.66 dB and 9.7%/dB, respectively. The SRT of HI children were strongly positively correlated, in a statistically significant manner with the PTA in both the test and the retest sessions (test: r=0.750, P < 0.0005; retest: r=0.753, P < 0.0005). The Spearman correlation of the rankings of SRT values and the slope values was 0.998 and 0.997 respectively for the HI and 0.939 and 0.88, for the NH group, indicating very low variability across the test and retest sessions. In addition, the analysis of variance (ANOVA) of the average SRT in NH children and the SRT residuals in the HI group indicated that the different sentences were of the same difficulty within each group. (($F(9,81)=0.401$, $p=0.930$ and $F(9,93)=2.241$, $p=0.025$ respectively).
**Conclusions**: A validated sentence based speech audiometry test was created in Greek for the first time. SRT and S50 values for both NH and HI children are comparable to similar tests developed in other languages.

**Keywords:** Speech audiometry, Picture-related sentences, Greek language

## Introduction

Speech audiometry tests are designed to assess hearing ability by presenting balanced lists of linguistic items (i.e., words or sentences) to listeners. The listener responses, which are obtained through this process, form a speech audiogram showing the ratio of correct responses as a function of the intensity of the speech. Speech audiometry tests are useful in obtaining a reliable indication of a patient's ability to understand and reproduce aspects of language, in deciding on the appropriate treatment (particularly in helping to choose between possible hearing aids) and in educational placement as far as the underlying hearing handicap is concerned. They have also been used for diagnosis as, for example, for distinguishing between VIIIth nerve and cochlear patterns of dysfunction, for example (Jerger and Jerger, 1967), and prediction of hearing level.

Conventional speech audiometry uses two types of linguistic material: lists of words and lists of sentences. Typically, the word lists used are “phonemically balanced”, i.e., they are selected to reflect the phonemic composition of everyday speech. As the perception of words in isolation is not necessarily a good predictor of the perception of everyday speech that consists of sentences, lists of sentences have also been used in speech audiometry.

The advantage of word-based tests is that they can be administered faster than sentence-based tests and thus they may limit the fatigue effect, which could influence the patient’s scores, and is more commonly used in children (Bamford, et al., 1979). The use of sentence lists, on the other hand, has the advantage of enabling perception in context, due to the redundancy provided by the “rules” of context, both grammatical and semantic, that are a feature of words in sentences but not words in isolation (Mendel, 2008). In general, the increased redundancy due to the larger number of items in sentence lists, increases the slope of the audiogram, reduces variability, and increases accuracy of speech reception estimates (Bell and Wilson, 2001). Furthermore, the use of sentences allows a systematic investigation of the time domain, as sentences are of sufficient duration to permit alteration of the temporal characteristics of speech (Speaks and Jerger, 1965; Mendel 2008). The sentences used in sentence-based tests may be synthetically generated or identified through syntactic and grammatical analysis of the language that the targeted subjects of the test use (sentence matrix approach (Hagerman, 1982)).

It is essential that the linguistic material used in speech audiometry tests is representative of the whole language spectrum and is within the linguistic ability of the listener (Mendel, 2008). Further considerations in developing speech audiometry tests for children relate to the requirements that the words that make up the sentences should be within their vocabulary and commonly occurring, in order to minimise the effect of word frequency on intelligibility (Howes, 1957); the grammar of the sentences should not exceed their grammatical ability; and the length of each sentence should not exceed their memory span. Test sentences should not be long and grammatically too complex but suitable for use with partially hearing children.

In the UK, the first speech test using sentences, known as "Manchester Sentence lists", was developed in 1957, and comprised of 5 lists of sentences of 100 key (Watson, T.J., 1957). In 1979, Bamford et al. (1979) developed the BKB test for partially hearing-impaired children. This test had 21 lists of sentences. Each list had 16 sentences of 50 key words. Nicquette et al., (2003) introduced a speech in noise version of BKN, known as BKB Speech in Noise (BKB SIN). BKB SIN consisted of 18 lists of pairs of sentences that are presented in a four-talker babble. In 1984, Jerger & Jerger (1984) developed the English Paediatric Speech Intelligibility (PSI) test.

Several other Non-English sentence tests for children have been developed using different methods for measuring speech intelligibility in quiet and against noise (Wagener et al, 2003; Plomp & Mimpen, 1979; Van Wieringen & Wouters, 2008; Ozimek et al, 2012; Zheng et al, 2009. The methods differ in the aspects such as the structure of materials, presentation level, details of the test procedure, type of interfering noise and presentation mode.

For the Greek language, there have been only word-based speech audiometry tests but no sentence based speech audiometry test. This paper presents a study whose purpose was to develop a Greek Sentence Based Speech Audiometry Test in quiet for hearing impaired (HI) children (G-SEBSAT). The main purpose of G-SEBSAT is to provide a measure of the overall auditory function of HI children of 6-14 years of age and support their rehabilitation through the use of hearing aids.

## Method

### *Data collection and vocabulary analysis for sentence lists*

The initial step of the study was the development of the sentence lists. The collection of vocabulary was based on showing pictures to hearing impaired (HI) children and asking them to describe what they saw. The pictures used were coloured drawings, covering a range of scenes and events or environments familiar to children that were selected from popular reading materials in Greek (Amery & Cartwright, 2002). The rational for choosing this material was to identify types and frequencies of words with which children were familiar with, and not to investigate the full range of vocabulary knowledge of HI children. Children and their responses were recorded and analysed.

Seventy-six children were recruited in this phase following approval by the local ethics committee and after obtaining informed consent from their parents. Inclusion criteria were age 6-14 years, with a pure tone audiogram (PTA) in the better ear of not less than 40 dB (averaged thresholds at 500, 1000 and 2000Hz), and at least able to cope with simple vocabulary when given contextual information. PTA methodology was based on the procedure recommended by the British Society of Audiology (BSA) (BSA, 2011) using an Aurical Audiometer with TDH-49 headphones. These selection criteria were similar to the Bamford-Kowal-Bench (BKB) test of Bamford et al. (1979). For each child, the following data were collected: (a) the cause of their hearing impairment, (b) the age at which the hearing impairment was diagnosed, (c) the type of the hearing aids fitted, (d) the parent occupations and (e) the type of schools (mainstream or special) attended. (a)-(c) were collected from hospital notes. (d)-(e) were as reported by parents. The average age was 9.28 years (SD=1.938) and the average best ear PTA was 59.40dB (SD=14.41). 46% had mild, 38% moderate, and 16% severe HL. The criteria used to categorise the type of HL were as defined by the audiometric descriptor categories of BSA (BSA, 2011). On average, the participated children were fitted with hearing aids at the age of 4.82 years (SD=2.26). The distributions of ages, HL type, HL aetiology, socio economic background and the school type of the 76 HI children used for language analysis are summarised in Table 1.

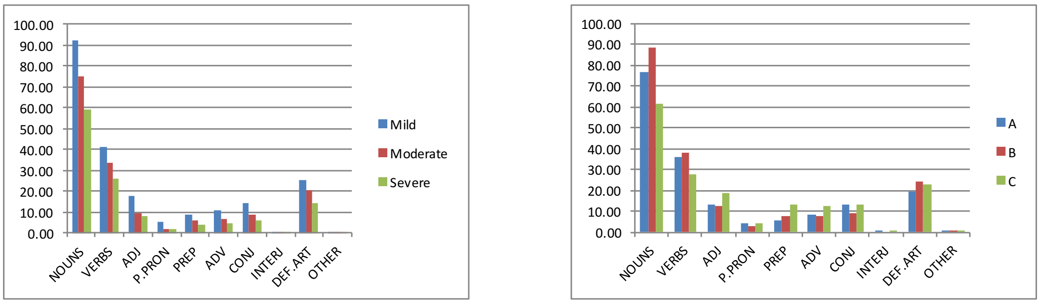
**Table 1.** Basic statistics of HI children. In age group, A is (6 to 8 years), B (9 to 11 years) and C (12 to 14 years). The meaning of HL types is: (ML: mild), (MO: moderate), and (SE: severe). The meaning of HL aetiology is: (UN: unknown), (PN: peri-natal complications), (GE: genetic), (FA: familial) (PR: pre-natal), and (HE: hereditary). The meaning of socio economic background is: (US: unskilled occupations), (PR: professional occupations), (SK: skilled occupations, (DR: deceased, retired or unemployed), and (MA: member of armed forces). The meaning of school types is (GS: General School) and (SS: Specialist School).

| *Age Group* | | | *HL Type* | | | *HL Aetiology* | | | *Socio Economic Background* | | | *School Type* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *VAL* | *N* | *%* | *VAL* | *N* | *%* | *VAL* | *N* | *%* | *VAL* | *N* | *%* | *VAL* | *N* | *%* |
| *A* | 31 | 41 | *ML* | 29 | 38 | *UN* | 44 | 58 | *US* | 13 | 17 | *GS* | 62 | 82 |
| *B* | 37 | 49 | *MO* | 35 | 46 | *PN* | 11 | 14 | *PR* | 19 | 25 | *SS* | 14 | 18 |
| *C* | 8 | 11 | *SE* | 12 | 12 | *GE* | 7 | 09 | *SK* | 31 | 41 | | | |
| | | | | | | *FA* | 7 | 09 | *DR* | 10 | 13 | | | |
| | | | | | | *PR* | 6 | 08 | *MA* | 3 | 04 | | | |
| | | | | | | *HE* | 1 | 01 | | | | | | |

During the interview meeting, each child was presented with seven pictures and was asked to describe and talk about them (Amery & Cartwright, 2002). Questions were avoided and non-picture specific prompts (e.g., "tell me what's happening here") were given. The recording of each subject's picture-description was subsequently transcribed and subjected to grammatical analysis for vocabulary and grammatical content.

A grammatical content analysis was carried out manually to determine the average syntactic and morphological structures of the sentences used by the HI children. This identified different vocabulary categories, namely nouns, verbs, pronouns, adjectives, adverbs, prepositions, definite articles, interjections, conjunctions and other. This was necessary to ensure that the sentences of the test would have the same grammatical content as those observed in the collected vocabulary.

Figure 1 shows the average frequency of use of the different vocabulary categories for HI children with different types of hearing HL and of different age groups. As the histograms show, the words with the highest overall frequency amongst the younger (group A) and most impaired children (severe HL) were nouns, verbs, definite articles, adjectives, conjunctions, adverbs and prepositions.




*(a) Average vocabulary frequencies by type of HL* *(b) Average vocabulary frequencies by age group*

**Figure 1:** Histograms of average frequency of use of different categories of vocabulary of 76 HI-children with different levels of HL and of different age groups. The types of HL shown are: Mild (average PTA in [40dB, 60dB]), Moderate (average PTA in (60dB, 80dB]) and Severe (average PTA in (80dB,95dB]). The age groups shown are: A ((6, 8] years range), B ((8,11] years range) and C ([11,14] years range).

*Grammatical content*

The grammatical structure of the spoken language of HI children was also analysed in order to ensure that the lists of sentences used in the test would be aligned with the capabilities of the children with the highest level of hearing loss.

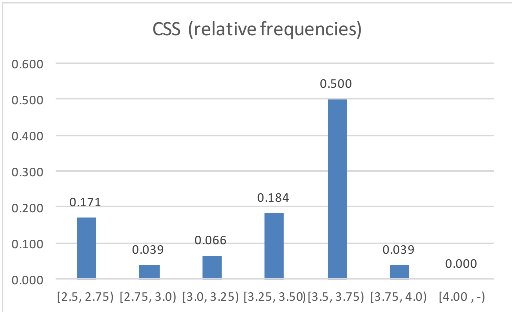
In order to describe the grammatical content, the methodology followed of Crystal et al., (1976) was used, according to which, analysis is to be conducted at two distinct levels: (a) the *clause level* that is concerned with the number and arrangement of subject, verb, object, adverbial and complement elements in sentences; and (b) the *phrase level* that is concerned with the occurrence and development of phrase structures within clause elements. Both these levels are important since clause level analysis shows the syntactic development of the child's language, whilst phrase based analysis shows the capability of the child to form more complex sentences.

The clause based development stage of HI children was measured based on the levels and indicators shown in the upper (i.e., Clause stage) part of Table 2 (the meaning of these indicators is that adopted by Crystal et al., (1976) and their meaning is as described in Appendix 2). More specifically, for each HI child we measured the number of responses that he/she produced under each indicator when presented with the pictures underpinning the test. The overall clause stage score (CSS) of a child was calculated as the weighted average of the stage level indicator frequencies, i.e., according to the formula: $CSS = \sum_{I=1,\ldots,6} I \times NR_I$ where I is the stage indicator and $NR_I$ is the total number of the instances of the different stage indicator that the child produced in his/her responses. The relative frequencies of the HI children CSS scores are shown in part (a) Figure 2.

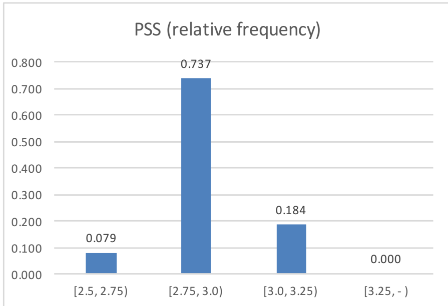
**Table 2.** Indicators used to assess the clause based and phrase based stage development of HI-children and average number of responses per indicator across the 76 HI children in the parentheses next to each indicator.

| *Clause Stage* | *Clause Stage Indicators* |
|---|---|
| *1* | Exclamation (0.12), Command/Verb (0.66), Question (0.12), Verb Statement (2.41), Noun statement (5.49) |
| *2* | SV (6.24), VC/O (2.85), SC/O (0.53), AX (1.62), X (0.25) |
| *3* | X+S:NP (4.12), X+V:VP (6.34), SVC/O (20.70), VC/OA (0.93), SVA (7.62), NegXY (0.22) |

| | |
|---|---|
| *4* | XY+S:NP (16.91), XY+V:VP (12.88), OA (4.61), AAXY (1.99) |
| *5* | Coord.1 (10.49), Subord.1 (2.47), C/O (2.79), A.Comperative (1.42) |
| *6* | +NP-Indicator (1.25), +VP-Complex (0.17) |
| *Phrase Stage* | *Phrase Stage Indicators* |
| *2* | *DN (41.84), VV (2.17), AdjN (2.68), NN (0.38), PrN (1.64), IntX (0.70)* |
| *3* | *X+C/O:NP (1.86), X+A:AP (1.24), DAdjN (4.45), AdjAdjN (0.63), PrDN (11.92), NAdjN (0.42), Cop(5.31), Aux (12.82), Pron (17.20), PrPron (1.63)* |
| *4* | *XY+C/O:NP (12.09), XY+N:AP (6.54), N PrNP (0.09), PrDAdjN (1.67), XcX (4.47), NegV (1.01), 2 Aux (0.22)* |
| *5* | *Postmod.1clause (5.17), Postmod.1+Phrase (0.20)* |
| *6* | *NP/Pron (0.03), NP/Adj.Seq. (0.05)* |




*(a) Clause Based Stage Development Scores*




*(b) Phrase Based Stage Development Scores*

**Figure 2.** Histograms of clause based and phrase based stage of HI children development.

The phrase based development stage of HI children was based on the levels and indicators shown in the lower (i.e., Phrase based) part of Table 2. More specifically, for each child we measured the number of responses that he/she produced under each indicator when presented with the pictures underpinning the test. As in the case of CSS, the overall phrase stage score (PSS) of a child was calculated as the weighted average of the stage level indicator frequencies (i.e., PSS = $\sum_{J=2,\ldots,6} J \times NR_J$ where J is the phrase stage number and $NR_J$ is the total number of the instances of the different indicators of the particular stage that the child produced in his/her responses).The relative frequencies of the HI children PSS scores are shown in part (b) of Figure 2.

*Development of actual sentence lists*

The development of the sentence lists was based on the vocabulary and the grammatical analysis. More specifically, with regards to the vocabulary we used words with high overall frequency amongst the younger and most impaired children, including nouns, verbs, definite articles, adjectives, conjunctions, adverbs and prepositions. To be eligible, a word should have appeared at least twice in the total collected vocabulary.

The frequency of used grammar structure in sentences was aligned with the frequency of these structures in the analysis of the spoken language of HI children. With regards to clause structure, we used sentences structured according to the two indicators of clause based stage 3, which have had the highest average use (i.e., SVC/O, SVA), and the most frequently used indicator of clause based stage 2 (i.e., SV) and clause based stage 4 (i.e., XY+S: NP). This is because, as shown in the figure 2, 53.9% of the children were between stage 3 and stage 4, i.e., they have had a CSS score in the range [3.5, 4.0), 28.9% of the children in the range [2.75, 3.5) and 17.1% of the children were in the range [2.5, 2.75). Hence, the predominant clause based stage amongst the HI children used in our study was stage 3, followed by stage 2 and stage 4. With regards to phrase structure, sentences were constructed based on phrase structures following the three indicators of phrase-based stage 3, which had the highest average use amongst the HI children. This was because, as shown in **Figure 2**, 73.7% of the children were between stage 2 and stage 3, i.e., they have had a PSS score in the range [2.75, 3.0), 18.4% of the -children have had a PSS in the range [3.00, 3.25) and 7.9% of the children were in the range [2.5, 2.75). Hence, the predominant phrase based stage was stage 3, followed by children in stage 3 to 4 and children in stage 3 to 2.

Overall, the test was composed of 10 sentence lists. Eight of these lists contained 16 sentences and two lists contained 17 sentences. The latter two were introduced to ensure completeness with regards to the description of the relevant picture scenes and have the same grammatical structure as the former. We used plural as well as singular forms of nouns, adverbs, adjectives, prepositions and articles. Each of the 10 lists contained 50 “key” words, i.e., words carrying most of the meaning of the sentence. The number of key words per list was controlled as a measure of keeping the list difficulty at the same level. The length of each sentence did not exceed 8 syllables and had a minimum of 4 syllables.

The test's lists, sentences and key words can be found in: https://drive.google.com/file/d/0B54WXEcaxIIMUE5CMnZmOG5NZ1E/view?usp=sharing.

*Recording, sentence presentation process and scoring*

The material was presented by a male native speaker of standard Modern Greek with no speech or hearing impairments, a good intonation, clear articulation and good voice quality. The speaker was recorded reading the lists of selected sentences in a non-reverberant and soundproofed room.

One-minute duration of 1 KHz calibration tone was recorded at the beginning of the CD. Sentences were recorded at deflection to zero of the volume unit (VU) meter, and thus the maximum speech peaks were at the same level as the calibration tone (judged on VU meter). Recordings were made directly to a CD-player. A warning noise (a low-pass noise band) of 2-second duration was added prior to each sentence, at a level slightly lower to the calibration tone. There was an interval of approximately 1 second between the cessation of the warning signal and the start of the sentence. The signal was a broad-spectrum noise consisting of frequencies mainly below 800 Hz, as most HI children tend to have better hearing at lower frequencies and also a bandwidth as wide as 800 Hz is likely to produce loudness summation at least in listeners with normal hearing (Zwicker & Scharf, 1965). The interval between the end of each sentence and the onset of the next warning signal was approximately 5 seconds, to allow sufficient time for the child to respond.

The pre-recorded sentence lists were presented to children using and an IMG Stage Line (3-beam laser pickup system). There was no broadband noise as the test was in quiet. The equipment used for the sentence lists testing was an Aurical Plus clinical audiometer of GN Otometrics with a set of Yamaha-Logitech Surround Sound Speakers Z506. The position of loudspeakers relative to the child was based on BSA guidelines on the acoustic of Sound Field Audiometry (BSA, 2008). The maximum levels of ambient noise, and reverberation time in the test room met the requirements defined in ISO8253-2 for sound field-testing. A high-quality sound level meter conforming to type 1 of IEC 60651 was used to measure ambient noise against those levels specified in ISO 8253-2.

Lists were scored by the percentage of the "key" words reported correctly.

*Validation*

A key step towards the validation of our test was to investigate whether the lists were of equal difficulty amongst HI and NH children and therefore, whether the choice of a specific list in the assessment of a child’s speech intelligibility could influence the speech intelligibility threshold detected for it. An analysis of the variability of the speech intelligibility responses was obtained from separate applications of the test (in *test* and *retest* sessions) for HI children and for NH children.

The above types of analysis were in line with practice in the case of speech audiometry tests for languages that were developed in the absence of any other adequate reference baseline for validating their results, and have been carried out for other speech audiometry tests of this type (e.g., in the BKB test by Bamford et al. (1979)).

The methods used for carrying out the above types of validation are described in detail below

*(a) Variability of list difficulty amongst NH children*

To assess the equality of the list difficulty amongst NH children, we selected a group of 10 NH children aged from 6-14 years, who were attending normal schools. Except from their hearing ability, the selection of NH children was based on the very same criteria as the HI children. The average PTA of these children across 500 Hz, 1 KHz and 2 KHz varied from 0 dB to 5 dB (2 children). Each NH child listened to all 10 different lists of the test. The lists were presented at the same speech level (i.e., 20dB), except in the case of the 2 NH children who had an average PTA of 5dB. To those 2 children, the lists were presented at the speech level of 25dB. The level chosen for each child was the one at which the child attained a speech intelligibility ratio in the region of 50% for each list. As suggested in Bamford & Bench (1979), this level minimizes "ceiling" and "floor" effects. Children were assessed by a PTA test prior to listening to the sentences and were given short breaks of equal length after the presentation of each list to ensure that could remain attentive for all lists. The lists were presented without pictures in a quiet room.

*(b) Variability of list difficulty amongst HI children*

The level of difficulty of the different test lists was also assessed for HI children. This was based on data collected from 45 HI children, who were chosen based on their age from 6-14 years, with a pure tone audiogram (PTA) in the better ear of not less than 40 dB ISO (averaged thresholds at 500, 1000 and 2000Hz), and at least able to cope with simple vocabulary when given contextual information. The group of HI children that were used in the validation of the test was different from the group of HI children, who were used to study the language development and inform the construction of sentence lists of the test. It should be noted, however, that the two groups had had HI children with similar profiles in terms of hearing loss, age, socio economic background, types of schools and language development.

The examination of differences in the difficulty level of different lists in the case of HI children was based on two separate sessions, i.e., a test and a retest session. Both sessions used the same procedure. This procedure started with conducting a PTA test and recording the outcome in both ears of each child. Following that, using free field condition, each child was presented with one randomly selected list for practice purposes, and was asked to repeat the sentences within the list. The practice list was presented to the child's better ear. Along with the list, the child was presented with the pictures that the different sentences of the list were related to. The initial list enabled the child to practice and allowed the tester to estimate the speech level range over which the intelligibility curve of the child was likely to lie.

The child was then presented with an additional four to six test lists, following the training list. Lists were presented at different levels of intensity. More specifically, the first list was presented at initial intensity level (IIL) set at 30dB above the child's average best ear PTA measured at 500Hz, 1 KHz and 2 KHz. The subsequent lists were presented at IIL+10db (or 90dB max), IIL – 10dB, IIL – 20dB etc., up to the point when the child was unable to repeat any key words correctly. A pause of 2 seconds was made between presenting different sentences in a list. For each of the test lists, we computed the child's score as the ratio of the "key" words of the list that the child repeated correctly.

Each test/retest session was completed in approximately two hours. The sessions were conducted in a quiet room, and the tester tried to ensure that the listening conditions remained constant and that the children remained attentive and fully engaging for all lists.

For each of the lists presented to each child, we recorded the speech response ratio, i.e., the ratio of the key words of the list that the child repeated correctly after presented with the sentences of the list. On the speech reception ratios obtained for each child, we attempted the fit of a linear-log regression curve. This curve was fitted on data pairs of the form *(SIR, ln(dB))* where SIR is the speech intelligibility ratio for the list and *ln(dB)* is the natural logarithm of the dB level at which the sentences of the given list were presented to the child. For each child, we obtained two sets of *(SIR, dB)* data pairs: one set for the test (i.e., the *(SIR_T, dB)* pairs) and one set for the retest (i.e., the *(SIR_RT, dB)* pairs).

Of the overall 45 test and retest logit curve pairs that were fitted to the (SIR, dB) data, we restricted our attention to curves produced by at least 4 *(SIR, dB)* data points in each of the test and the retest sessions, and were statistically significant at level of $p < 0.05$, for both the test and the retest data. In total, 23 pairs of test, retest logit curves satisfied these two conditions. These intelligibility curves were deemed to provide a baseline for each set of data, and, in line with corresponding baseline analysis carried out in the BKB test (Bamford and Bench, 1979), we used them to identify systematic trends in the residuals of the fitted curves, i.e., the differences between the speech reception ratios predicted by the fitted curve and the actual speech reception scores observed for each child.

The aim of this analysis was to examine the distributions of the residuals of the 10 different lists across all children and check if any of the lists had significantly larger positive residuals (i.e., residuals above the baseline provided by the corresponding fitted curve) that would be indicative of an easier list, or significantly lower residuals (i.e., residuals below the baseline provided by the corresponding fitted curve) that would be indicative of a more difficult list. This analysis was based on applying single factor ANOVA on the residuals of the different lists across the 24 cases of HI children with statistically significant intelligibility curves. ANOVA was applied separately to the residuals of the intelligibility curves obtained for the tests and to the residuals of the intelligibility curves obtained for the retests.

*(c) Variability between test and retest sessions for HI children*

The third type of analysis focused on investigating whether there was any significant variability of the outcomes of the test when applied to the same child on separate occasions but under the same conditions (i.e., using the same sentence list and under the same listening conditions). This analysis was also carried for both HI and NH children.

The analysis for HI children was based on the logit curves, which were fitted to the speech intelligibility responses obtained from the HI children as described in (b) above. Based on the two curves fitted to each child's test and retest data, we estimated the speech response threshold (SRT), i.e., the dB level at which the child was expected to produce 50% of correct responses when presented with a list of sentences. This was estimated using the formula $SRT_E = e^{(0.5 - a)/b}$ where a, b are the estimated parameters of the logit regression curve fitted to the test or retest data, i.e., the curve SRR = a + b*ln(dB)).

*(d) Variability between test and retest sessions for NH children*

A test-retest variability analysis was also conducted for the 10 NH children. In this case, however, each child was initially presented with a randomly selected practice list and subsequently with all the remaining 9 lists as test lists. The practice list was presented at the IIL level calculated as in the case of HI children. The subsequent test lists were presented at intensity levels increasing in steps of 5 dB above IIL and up to 50dB first, and then at intensity levels decrease in steps of 5 dB from IIL and down to 5dB. This design allows comparisons between all lists, not just comparisons within certain four-six lists, as was the case with the data from the HI children.

The SRTs in the case of NH children were obtained by fitting a straight line to the two data points enclosing the targeted 50% response rate, i.e., the two consecutive data points for a child $(R_L, dB_L)$ and $(R_H, dB_H)$ such that $R_L < 0.5$ and $R_H > 0.5$. The slope of the fitted line was computed by the formula $slope = (R_H - R_L)/(dB_H - dB_L)$. Subsequently, the expected SRT, i.e., the dB level at which a 50% rate of correctly recalled keywords of the list was expected to be achieved by the child, was computed by the formula: $SRT = ((0.5 - SIR_L) / slope) + dB_L$.

## Results

### *Basic statistics on SRT and speech intelligibility curve slopes*

Table 3 shows the average SRTs obtained from the fitted speech intelligibility curves in the test and the retest and the pure tone audiometry (PTA) scores, as recorded at test and retest sessions for the 23 HI children, who satisfied the inclusion criteria of this analysis, i.e., HI children who gave at least 4 responses at different dB levels in each of the test and retest sessions and have had statistically significant SRT – dB logit curves fitted to these data sets. The 23 children who provided a sufficient number of responses did not have any statistically significant differences in terms of age, HL or speech language ability from the HI children who did not produce a sufficient number of responses. It also shows the average slopes of the speech intelligibility curves at the SRT level (i.e., the level at which 50% of the responses were correct).

**Table 3.** Average speech response thresholds (SRT), PTA outcomes and SRT curve slopes for 50% correct response level, as recorded at test and retest sessions for 23 HI children.

| | *TEST* | | | *RETEST* | | |
|---|---|---|---|---|---|---|
| | *PTA (dB)* | *SRT(dB)* | *$S_{50}$ (%/dB)* | *PTA (dB)* | *SRT (dB)* | *$S_{50}$ (%/dB)* |
| *mean* | 54.29 | 65.27 | 3.11 | 53.90 | 65.10 | 3.13 |
| *std* | 10.18 | 13.31 | 1.04 | 10.16 | 13.38 | 1.05 |
| *min* | 30.00 | 31.96 | 1.83 | 30.00 | 31.55 | 2.00 |
| *max* | 68.75 | 86.26 | 6.02 | 68.00 | 86.25 | 6.00 |

The SRT of HI children were strongly positively correlated, in a statistically significant manner with the PTA in both the test and the retest sessions (test: r=0.750, P < 0.0005; retest: r=0.753, P < 0.0005).

Table 4 shows the average speech response thresholds obtained from test and retest sessions for the 10 NH children. It also shows the average pure tone audiometry (PTA) scores at 500Hz, 1 KHz and 2 KHz for the best ear of these children that were obtained prior to the test, and the slopes of the speech intelligibility lines at the SRT level (i.e., the level at which 50% of the responses were correct).

**Table 4.** Average speech response thresholds (SRT) for 50% correct responses level, best ear PTA and slopes (%) in test and retest sessions for 10 NH children.

| | *TEST* | | | *RETEST* | | |
|---|---|---|---|---|---|---|
| | *PTA (dB)* | *SRT(dB)* | *$S_{50}$ (%/dB)* | *PTA (dB)* | *SRT (dB)* | *$S_{50}$ (%/dB)* |
| *mean* | 2.50 | 17.66 | 9.700 | 2.20 | 17.88 | 9.30 |
| *std* | 1.18 | 2.96 | 3.00 | 0.82 | 3.82 | 2.20 |
| *min* | 1.25 | 12.30 | 4.00 | 1.25 | 12.17 | 6.00 |
| *max* | 5.00 | 22.17 | 13.8 | 3.75 | 26.00 | 12.00 |

*Variability of list difficulty amongst NH children and amongst HI children*

Table 5 shows the basic statistics of SRT values across lists and across test and re-test sessions for HI and NH children.

**Table 5.** Statistics of SRT variability measures

| | *SRT variability across lists* | | *SRT variability in test, re-test sessions* | |
|---|---|---|---|---|
| | *HI (res)* | *NH* | *HI* | *NH* |
| mean | -0.003 | 0 | -0.165 | -0.21 |
| std | 0.041 | 0.33 | 0.525 | 0.409 |
| min | -0.067 | -0.10 | -1.046 | -3.82 |
| max | 0.062 | 0.60 | 0.891 | 0.68 |

The analysis of variance (ANOVA) of the response ratios of the NH children across the different lists indicated no statistically significant differences between the average SRTs of the different sentence lists (F(9,81)=0.401, p=0.930). It also showed no statistically significant differences between the average SRTs of the different NH children (F (9, 81)=1.075, p=0.389). Thus, the sentence lists of the G-SEBSAT test can be considered to be of the same difficulty for NH children.

The analysis of variance of the SRT residuals of HI children (i.e., the residuals of the speech perception ratios of HI children above the predicted value provided by the fitted speech intelligibility curve) showed that the differences of these residuals between lists were not statistically significant in either the test ($F(9,93)=2.241$, $p=0.025$) or the retest sessions ($F(9,83)=2.488$, $p=0.013$). Thus, the sentence lists of the G-SEBSAT test are of the same difficulty for HI children.

*Variability of SRTs between test and retest sessions for HI children*

The correlation coefficient of the SRT values obtained for HI children in test and retest sessions was strongly positive and statistically significant ($r=0.99$, $p<0.005$). $S_{50}$ slopes across test and retest sessions were also significantly correlated ($r=0.98$, $p<0.005$). The Spearman correlation of the rankings of SRT values and the slope values was 0.998 and 0.997, respectively, indicating very low variability across the test and retest sessions.

*Variability between test and retest sessions for NH children*

The correlation coefficients between the SRT and between the slope values obtained for NH children in test and retest sessions were strongly positive and statistically significant ($r_{SRT}=0.959$, $p<0.005$; $r_{S50}=0.962$, $p<0.005$). The Spearman correlation coefficients between the rankings of the SRT-T and SRT-RT values and between the rankings of the slope values were 0.939 and 0.88, respectively. These coefficients indicated very low variability of the test outcomes across the test and retest sessions for NH children.

## Discussion

*SRTs and slopes*

The average SRT value for HI children detected in our study is within the range of values for this indicator that have been found in speech audiometry tests in other languages, as shown in Table 6. More specifically, the average SRT value for HI children in our study was 65.27 and is within the range of average STR values found in the BKB test (85.27dB) and OlKiSa test (53.4dB) The range of SRT value of the PPMST test were considerably lower (0.4 to 1.5 dB) but these are not directly comparable to ours as the PPMST test used an adaptive SRT calculation method that is appropriate for speech audiometry in noise tests.

**Table 6.** SRT and $S_{50}$ slope values found in Speech Audiometry Tests for Children ("?" used where the corresponding values for a test have not been reported)

| | *SRT(dB) [ave ± std]* | | *$S_{50}$(%/dB) [ave ± std]* | |
|---|---|---|---|---|
| *TEST* | *HI* | *NH* | *HI* | *NH* |
| G-SEBSAT[Children, 6-14 years, in quiet, Greek] | 65.27 ±13.32 | 17.66 ± 2.96 | 3.1 ± 0.60 | 9.7 ± 3 |
| BKB Test[Children, 8-15 years, in quiet, English] (Bench et al., 1979) | 85.27 ±18.30 | 33.29 ± 3.68 | 2.82 ± 1.11 | 3.11 ± 0.79 |
| OlKiSa Test [Children, 4-10 years, in quiet, German](Weißgerberet al., 2012) | 53.4 ±19.6 | ? | 6.8±3.4 | 10±? |
| Polish Paediatric Matrix Sentence Test (PPMST) [Children, 3-6 years, in noise, Polish] (Ozimek et al., 2012) | 0.4(±3.4) – 1.5(±1.8) | 5.9 (±5.5) – 3.4(±2.1) | ? | 12.9 – 19.3 |

The standard deviation of STR values of G-SEBSAT was lower than the relevant measures of the BKB and the OlKiSa tests (i.e., 13.22 vs. 18.30 and 19.60). However, the ratio of the standard deviation over the average of the STD values in our test was comparable to the relevant ratio of the BKB test (0.20 vs. 0.21).

In the case of NH children, the average SRT value of G-SEBSAT was lower than the relevant value of the BKB. This difference may be related to the different characteristics of the NH children used in the tests, as methodologically G-SEBSAT was developed in the same way as BKB.

The average $S_{50}$ value for HI children in our study is 3.1%/dB. This was also within the range of the average $S_{50}$ values found in the BKB test (2.82%/dB) and OlKiSa test (6.8%/dB). This presents a significant drop in the discrimination function of the G-SEBSAT test across NH and HI children. However, similar outcomes have been identified for other tests (Weißgerber et al., 2012).

SRT variability across lists and across different sessions was very low for both NH and HI children in our study. Furthermore, the analysis of variance of the variability across lists and correlation of SRTs across test and retest sessions that were discussed in the *Results* section indicated no statistically significant differences. Thus, despite the absence of an absolute baseline for the Greek language for comparing the outcomes of the G-SEBSAT test, the results of this study demonstrate a level of robustness for the tests. The absence of SRT variability across test and retest sessions was in line with what was observed in the BKB test, which was developed and validated using the same methodology as G-SEBSAT (BKB's validation showed statistically significant differences between SRTs of different lists).

*Comparison with other Sentence Based Speech Audiometry Tests for Children*

The OlKiSa test (Weißgerber et al., 2012) has been developed for HI children in the age range of 4 to 10 years and tests speech perception in quiet. Unlike G-SEBSAT, this test has not been based on an analysis of word types or the syntax structure of German and does not include complete sentences. It contains pseudo sentences formed following a grammatical pattern of "numeral-object-adjective" (e.g., four red flowers). Also, it is not clear whether the selected language material corresponded to the minimal or average ability of children in the particular age range. Finally, there has been no analysis of the sensitivity of OlKiSa results across the lists of the test or across test and retest sessions.

The PPMST test (Ozimek et al., 2012) has been developed for testing speech intelligibility in NH and HI children in the age range of 3 to 6 years in noise. The test is based on matrix sentence approach using a fixed grammar of “subject-verb-object” pattern of 256 generated sentences.

The BKB picture related test (Bench, et al., 1979) has been developed for HI children in the range of 8-15 years, in quiet. Like G-SEBSAT, this test has been based on an analysis of words type and syntax structure of English and includes complete sentences, corresponding to the minimal ability of children in the particular age range.

*Comparison with other Greek Speech Audiometry Tests*

The sentence based test speech audiometry test for hearing impaired (HI) children that is presented in this paper is to the best of our knowledge, the first of this type for Modern Greek.

All other Greek speech audiometry tests that have been developed have been for adults, are word-based and test speech reception in quiet. In particular, Kogias (1961) developed a speech test, consisting of 6 lists of Consonant-Vowel-Consonant (CVC) balanced words. Manolidis (1964) developed 5 lists of phonetically balanced noun words. Iliades et al., (1978) developed a speech test consisting of 24 lists of bi-syllabic words. In 2006, Iliadou et al (2006) developed a speech test consisting of 3 lists of 50 bi-syllabic and phonetically balanced Modern Greek words each for use in word recognition. Trimmis et al. (2006) developed word lists for speech presented above the threshold of hearing of word recognition testing. The test included 4 lists of words comprised of bi-syllabic phonemically balanced

(PB) words. Lyzenga et al., (2009) developed a speech test consisted of 3 lists of digits, known as the "digit-triplet test" in Modern Greek.

*Limitations of our study*

G-SEBSAT is the first test of this type for Modern Greek, to the best of our knowledge. This very fact posed the main challenge in developing the test as there was no baseline to compare the results of our study. To overcome this difficulty, we carried out a sensitivity analysis of the speech reception thresholds (SRT) detected by the test across test and re-test sessions, as in the BKB test (M. Bamford et al., 1979).

Further challenges that were encountered in developing the test were related to: (i) finding a large number of HI children as such children in Greece may attend both specialist and ordinary schools and may have not been diagnosed as such and issued hearing aids, (ii) the inability to use computerized analysis of the grammatical and vocabulary content of the descriptions of the drawings used in the test due to the absence of relevant software, and (iii) the lack of non-verbal I.Q. (WISC performance scale) test results. To address (i) and (ii), we recruited HI children from both specialist schools and non-specialist schools and analysed drawing descriptions manually, respectively. As for (iii), our decision was not to use I.Q. test results, because such tests may only be conducted in specialist schools in Greece and only by psychologists appointed by the Greek Ministry of Education. This creates a limitation for our results that should be addressed in future research.

## Conclusion

A speech audiometry test was created in Greek for the first time. Test was based on picture related sentences, based on research in children with mild, moderate and severe hearing loss.

To validate the test, we analysed: (a) the equality of the difficulty of the different lists of the test amongst children with normal hearing, (b) the equality of the difficulty of the different lists of the test amongst partially hearing children, and (c) the variability of the speech intelligibility thresholds obtained from separate applications of the test (test and retest). This analysis indicated that the different lists were of equal difficulty both for NH children and for children with hearing impairment, and that different executions of the test indicated very small differences in speech intelligibility thresholds that were not statistically significant.

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APPENDIX 1(example of a list)

## THE PICTURE-RELATED (PR) SENTENCE LISTS

### *PR Sentence List 1 (50 Key words)*

**Το αγροκτημα**

Ο βοσκος φυλαει τα προβατα.
Τα παπακια κολυμπουν στη λιμνη.

**Το παρτυ**

Το δωματια ειναι γεματο με μπαλονια.
Το τραπεζι ειναι γεματο με γλυκα.
Το αγορακι κρυβεται κατω απο το τραπεζι

**Στο σπιτι**

Το αγορι πλενει τα δοντια του.
Η μητερα κατεβαινει τη σκαλα.

**Η κουζινα**

Η γατα ειναι πανω στο ντουλαπι
Το κοριτσι ταιζει το σκυλο της.

**Στο σχολειο**

Η δασκαλα ειναι θυμωμενη.
Το αγορι κολλαει τα φυλλα στο χαρτι.
Ο μαθητης παιζει με το πηλο.

**Η ακρογιαλια**

Το κοριτσι χτιζει πυργους στην αμμο.
Το παιδι παιζει με την αποχη.

**Το νοσοκομειο**

Η νοσοκομα ετοιμαζει το φαρμακο.
Το αγορι εχει βαλει θερμομετρο.
Ο γιατρος φοραει τη μασκα του.

APPENDIX 2 (Meaning of Abbreviations of Clause and Phrase Stage Indicators as used in (Crystal et al. 1976))

| *Clause Stage* | *Meaning of Abbreviations of Clause Stage Indicators* |
|---|---|
| | SV: subject-verb<br>VC/O: verb with complement or object,<br>SC/O: subject with complement or object<br>AX: adverbial and ne her element<br>X: and one other element<br>X (other element)+S (subject): NP (noun phrase)<br>X (other element)+V (verb): VP (verb phrase)<br>SVC/O: subject-verb with compliment or object<br>VC/OA: verb with compliment or object- adverbial<br>SVA: subject-verb-adverb<br>NegXY: negative with two other elements<br>XY+S: NP: two other elements + subject: noun phrase<br>XY+V: VP: two other elements + verb: verb phrase<br>OA: object-adverb<br>AAXY: adverb-adverb-two other elements<br>Coord.1: coordinate 1<br>Subord.1: subordinate 1<br>A. Comparative: adverbial comparative<br>+NP-Indicator: more than two noun phrases-indicator<br>+VP-Complex: more than two verb phrases-complex |
| *Phrase Stage* | *Phrase Stage Indicators with abbreviations* |
| | *DN: determiner-noun*<br>*VV: verb-verb*<br>*AdjN: adjective-noun*<br>*NN: noun-noun*<br>*PrN: preposition-noun*<br>*IntX: intensifier with any other phrase element*<br>*X+C/O: NP: one phrase element + complement or object*<br>*X+A: AP: one phrase element + adverb: adverbial phrase*<br>*DAdjN: determiner-adjective-noun*<br>*AdjAdjN: adjective-adjective-noun*<br>*PrDN: preposition-determiner-noun*<br>*NAdjN: noun-adjective-noun*<br>*Cop: copula*<br>*Aux: Auxiliary verb*<br>*Pron: pronoun*<br>*PrPron: preposition-pronoun*<br>*XY+C/O: NP: two other element + complement or object: noun phrase*<br>*XY+N: AP: two other element + noun: adverbial phrase*<br>*N PrNP: noun-preposition-noun phrase*<br>*PrDAdjN: preposition-determiner-adjective-noun*<br>*XcX: a connector between two phrase elements*<br>*NegV: a negated verb*<br>*2 Aux: 2 Auxiliary verbs*<br>*Postmod.1clause: post modified with 1 clause*<br>*Postmod.1+Phrase: post modified with more than one phrase*<br>*NP/Pron: non phrase or pronoun*<br>*NP/Adj.Seq.: noun phrase or adjective sequence* |