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Original article

Development of speech material for an Armenian speech recognition threshold test

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Abstract: *Introduction* — For the Armenian language, no standardized audiometric speech perception test is available. The purpose of this research was to develop, digitally record and evaluate an Armenian multisyllabic speech audiometry test, which can be used to measure speech recognition thresholds in Armenian native speakers.
Material and Methods — To create a homogeneous multisyllabic speech corpus, Armenian numerals from 10-100 with 2-4 syllables were selected as general sample and digitally recorded by a female native Armenian speaker. For equalizing the speech recognition threshold between the test items, the speech discrimination function for each numeral was subsequently evaluated by five normal hearing native Armenian listeners in an experimental study.
Results — Based on the phonemic structure of the Armenian language, 20 phonemically homogeneous test lists were created. The phoneme distributions of each test list correlated significantly and positively with that of the general sample (all Pearson moment correlation coefficients >0.960; all ps <0.001). Comparison of the phoneme distributions of test lists to that of the Armenian language showed that the test lists represent the language corpus quite well. After adjusting for actual threshold levels, speech discrimination functions are comparable between all numerals used.
Conclusion — The developed test lists are a phonetically homogenous representation of the Armenian language and serve as an appropriated base for future clinical measurements of speech recognition threshold in Armenian speaking listeners.

Keywords: audiometry, speech, speech recognition threshold (SRT) test, Armenian language.

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Introduction

Speech audiometry is one of the fundamental components of modern hearing diagnostics and audiological clinical research. It has become a basic tool in determining the degree and type of hearing loss, especially in identification of certain retrocochlear pathologies and auditory processing disorders [1-3]. In comparison to pure tone audiometry, which only gives information about absolute perceptual thresholds of tonal sounds, speech audiometry determines speech intelligibility and discrimination between phonemes and provides information about a person's communication abilities in natural listening environments. Speech test results are required to evaluate hearing device fitting, as well as assessment of the outcomes of hearing aid and cochlear implant rehabilitation [4-7].

One of the various measures used in speech audiometry is the speech recognition threshold (SRT). It is defined as “the minimum hearing level for speech at which an individual can recognize 50% of the speech material” [8]. The average SRT is approximately 7-9 dB above the average speech detection threshold, i.e., the lowest sound pressure level (SPL) at which the presence of a speech signal can be heard 50% of the time but can vary between 2 and 16 dB SPL. The SRT is correlated to the puretone hearing threshold average (PTA) of the lower frequency region. Discrepancies between SRT and PTA may occur in patients with auditory disorders, acoustic neuroma or exaggerated hearing loss [9, 10]. SRT is widely used in clinical routine as part of basic audiologic assessment [11, 12] for cross validation of puretone thresholds, measurement of communication disabilities, and as reference for suprathreshold speech audiometry (e.g., at 40 dB sensation level).

Spondaic words are generally recommended for SRT measures in the English language [8]. In German, lists of multisyllabic numerals are used [13-15]. Spondees are used in English [16], Polish [17] and Mandarin [18], while trisyllabic words are used in Japanese [19], Mandarin [20] and Spanish [21, 22]. Also matrix sentence tests are in available for different languages [23-26].

Compared with the rapid development of speech audiometry in Western Countries, the development of speech tests for Armenian speakers dropped behind. In Armenian, valid speech-audiometric materials is currently not available.

The Armenian language is an independent branch of the Indo-European language family. It is the official language of the Republic of Armenia and the Republic of Artsakh. Beside of Armenia with about 3 million inhabitants, Armenian is also widely spoken in the Armenian Diaspora, with about 8-12 million people living throughout the world. The largest communities outside of Armenia are in the Russian Federation, the Islamic Republic of Iran, the French Republic, the United States of America, Canada, the Syrian Arab Republic and the Lebanese Republic.

In order to provide valid and accurate speech intelligibility measurements, speech audiometry needs to be performed in the listener's native language [27]. Therefore, appropriate audiometric materials are essential. Clinical observations have shown that non-native listeners and patients with diverse linguistic backgrounds typically perform speech tests more poorly than native and/or monolingual hearing-impaired and normal-hearing listeners [28–31]. Consequently, each language should have its own speech materials [32].

Speech material should be developed based on similar, scientifically developed and recognized approaches, but with the regard for characteristics of every language. Simple translation of the developed speech materials from one to another language is inappropriate. This requires speech tests with well-defined properties, such as a careful selection of a sufficiently high number of speech items that are both representative for the underlying language and homogeneous with respect to their intelligibility [22]. Thus, using phonetically or phonemically balanced word lists with the statistically representative distribution of the phoneme incidence in conversional speech is important for the accuracy of the test results [33].

Recognizing the need for linguistically appropriate diagnostic tools, a number of speech tests in different languages (e.g., Russian, Danish, Brazilian Portuguese, Korean, Polish and Japanese among others) have been developed over the past several decades [34, 35, 17, 20]. In German speaking countries, the Freiburg speech intelligibility test [14, 15] is used as part of the standardization (Deutsches Institut für Normung) and as reliable standard for many applications [36, 37].

For speech audiometry, the item lists have to be phonetically balanced and the phoneme distribution should represent the phoneme distribution of the language. For the Armenian language, only a few speech corpuses have been developed. In the 1960s, the Linguistics institute of the Academy of Sciences of the Armenian Soviet Socialist Republic conducted a complete investigation of the peculiarity (acoustic, roentgenological, pronouncing etc.) of Armenian vowels and consonants, based on which high-, middle- and low-frequency word lists for adults and different age-group children have been developed in Armenian (Hovhannisyan's word lists [38]).

The aim of the current research was to develop, digitally record and evaluate speech-audiometric material that can be used to measure the SRT in quiet in native Armenian speakers.

Material and Methods

Selection and recording of test items

Test material was identified and recorded as reference recording that meets the regulatory normative requirements for speech test material [39]. To create a homogeneous multisyllabic speech corpus, Armenian numerals from 10 to 100 with 2-4 syllables were selected as general sample. Numerals with one, five or six syllables were excluded from the test lists in order to achieve larger uniformity in length of speech items and thus larger homogeneity in auditability.

After phonetic transcription, the phoneme distribution of the general sample was compared to that of the Armenian language. Twenty preliminary test lists were created, presenting each test item in a randomized order. After adjusting for equal phonetic distribution between the lists, 20 phonemically homogeneous test lists (each consisting of 20 numerals or 20 test items) were manually defined. The phonemic structures of the final test lists were compared with the phoneme distribution of the Armenian language [40] by calculation of the Pearson product-moment correlation coefficients.

As reference recording, the items of the final test lists were recorded three times by a trained female native Armenian speaker (Tsovinar Hayrapetyan) with clear pronunciation, a speed of 90-100 syllables/minute, as well as neutral emotion and effort. An U87 high-sensitivity microphone (Neumann, Berlin, Germany) was used in a sound proof chamber of the ''Multimedia Kentron TV'' broadcast studios (Yerevan, Armenia). A sampling rate of 44.100 Hz was used with an A/D rate of 16 bit. MATLAB software (Version 2015, Math Works, Natick, Massachusetts, USA) was used for all calculations and data processing steps. The recorded wave-file was cut and evaluated by the Armenian speaking author (SS) to identify the best recording of each test item regarding naturalness and clarity of speech. After removing time periods without speech, the remaining signal was ramped by a Hanning window with 10 ms of fading in and out times. Silence was added to the end of the signal to generate signals with equalized lengths of 1.5 seconds. After calculation of the root-mean square (RMS) of the signal amplitudes, the level of the individual test items was scaled to the mean RMS of all signals and checked to avoid clipping.

Subjects' measurements

To measure the speech intelligibility function for every test item, lists containing 10 randomized representations of each test item were presented to the right ear of five otologic normal and normal hearing subjects at a sound pressure level just above (+3 dB), below (-3 dB) and at the individual estimated 50%-speech reception threshold (SRT50) in quiet. The volunteers were recruited among students and patients and signed an informed consent form. The studies has been approved by the institutional ethics committee and has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. All participants were born and raised in Armenia and native Armenian speakers. Before testing, otoscopy and tympanometry was done and completed with normal results. Pure-tone audiometry thresholds were at 10 dB HL or better at frequencies 0.5, 1, 2 and 4 kHz and 15 dB HL or better at 0.25 and 8 kHz, respectively. The test items were presented by an AT900 audiometer (Auritec, Hamburg, Germany) using HDA 300 headphones (Sennheiser, Wennebostel, Germany) in a double-walled soundproof booth fulfilling the requirements of ISO 8253-1 [41]. In order to mimic the normal hearing audiometric test situation, no training of the subjects was provided.

Generation of final test lists

For every test item, speech intelligibility was fitted to a sigmoidal function by logistic regression. The sound pressure levels at the inflection points (SRT50) were calculated for each item and averaged across the subjects. SRT balanced test items were than created by adjusting the RMS level of each item according to the mean SRT50 in limits of +/-3 dB of the SRT averaged across all test items. Normal distribution was testes with the Chi-Square test.

For the final test, twenty lists of twenty SRT balanced items with equal distribution of the numerals were created. The stimulus onset asynchrony of the test was set to 5 s resulting in a total time of 100 s per list.

As calibration signal for the speech material, a noise similar to the CCITT (Comité Consultatif International Téléphonique et Télégraphique) noise that represents distribution of speech energy with a maximum at 800 Hz was created. Therefore, white noise was digitally created and filtered according to limits of 20 and 8.000 Hz. The RMS level was adjusted to the mean RMS level of all test items according to the normative restrictions [41]. The test items and the calibration signal were stored as single-channel signals to an audio compact disc to be used with standard clinical audiometers.

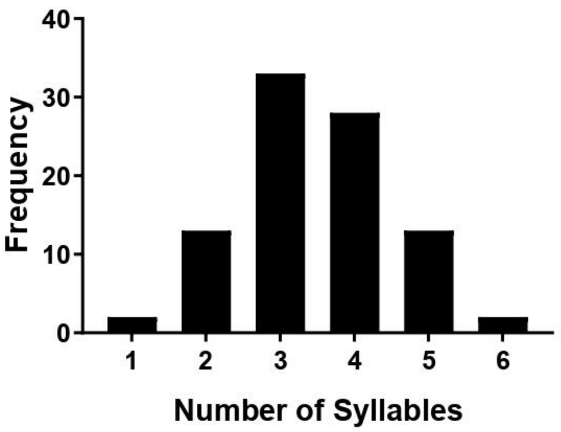

Figure 1. Syllabic structure of Armenian numerals from 10 to 100 (percentage of occurrence of mono- by, tri-, four- five- and six syllabic numerals among the all 10 to 100 Armenian numerals).

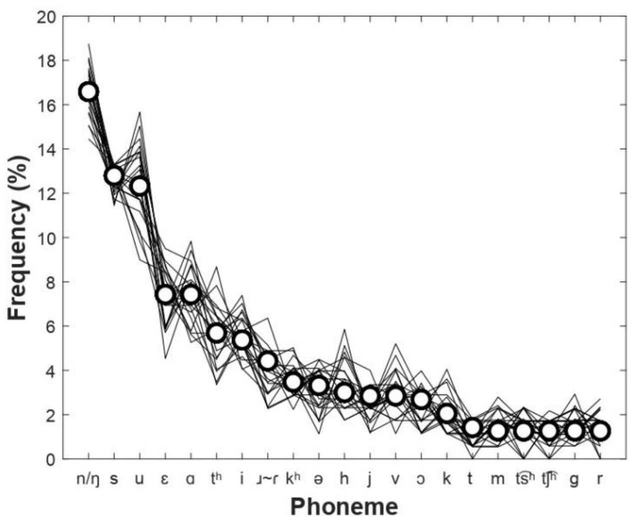

Figure 2. Phoneme distributions of the general sample (open circles) and of the 20 test lists (thin lines).

Table 1. Structure of Armenian Multisyllabic Numbers Test: 20 test lists with 20 numerals in each

Test lists																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Test items (numerals)																			
52	66	15	66	39	47	40	29	68	50	18	37	62	49	59	57	16	69	51	95
54	81	60	29	55	68	67	90	61	37	64	94	53	45	34	94	41	58	69	69
58	67	68	98	88	34	48	86	55	90	21	97	15	84	40	41	96	44	27	34
14	37	21	30	52	23	25	70	100	24	51	23	54	94	36	53	46	86	46	50
15	23	70	95	40	87	41	66	86	58	85	99	82	55	49	23	99	23	91	61
80	21	29	96	24	56	61	38	95	61	45	16	90	86	64	45	24	81	84	65
48	45	53	61	45	88	56	85	27	45	31	21	49	23	11	69	65	36	36	56
21	11	61	46	82	45	65	91	31	91	61	55	22	29	51	81	91	65	55	18
82	54	46	14	31	61	69	22	53	35	70	11	14	98	47	65	18	68	61	17
85	26	88	16	57	41	99	25	40	65	90	25	81	12	68	67	50	85	96	85
17	91	54	67	51	53	91	81	18	47	12	24	100	34	65	80	86	83	83	51
61	94	47	27	84	35	46	83	46	14	34	66	52	61	31	84	53	84	16	63
86	99	90	82	63	28	38	18	89	99	15	15	31	53	91	47	62	16	89	55
26	96	55	84	41	96	36	51	38	28	26	68	56	82	95	52	28	34	85	24
49	65	48	85	27	19	37	100	29	44	29	35	46	97	30	64	98	62	68	81
51	34	40	87	19	54	58	65	25	17	44	51	97	44	41	60	29	57	25	13
81	15	91	40	61	46	88	49	58	38	58	83	40	60	100	70	63	97	35	83
23	38	82	28	58	70	12	87	94	100	27	84	38	47	16	85	37	26	58	53
70	40	96	23	54	13	98	88	22	15	96	59	91	65	99	51	67	60	40	25
99	80	38	45	69	39	80	35	56	53	46	63	89	46	86	55	87	89	99	86

Results

Figure 1 shows the distribution of syllables in the corpus of Armenian numerals from 10 to 100. Monosyllabic and six syllabic words occurred with a percentage of 2.2% each, 14.3% of the numerals were two syllabic, 36.3% three syllabic, 30.7% four syllabic, and 14.3% five-syllabic ones. All of the two- to four-syllabic numerals were selected and included to create the test lists.

The phoneme distribution of the selected numerals (general sample) according to symbols of the IPA phoneme alphabet [42] is shown in *Figure* 2. The most frequent phonemes are the consonants [n/ŋ] and [s] with frequencies of 16.6% and 12.8%, respectively. The most frequent vowels are [u] (12.3%), followed by [ɛ] and [ɑ] (7.4% each). The frequency of the other phonemes varies from 5.7% to 2.0%. The most rare phonemes are the consonants [m], [t͡sʰ], [t͡ʃʰ], [g] and [r] with frequencies of 1.3%. Based on this phonemic structure, 20 phonemically homogeneous test lists with 20 numerals in each were created (*Table* 1). The phoneme distributions of those test lists are also shown in *Figure* 2. The phoneme distributions of each test list correlated significantly and positively with that of the general sample (all Pearson moment correlation coefficients > 0.960; all ps 0.001).

Figure 3 shows the phoneme distributions of the test lists and general sample in comparison to that of the Armenian language corpus mean [40]. Both phoneme distributions correlated significantly and positively (Pearson moment correlation coefficient = 0.998, p<0.001). From the 36 phonemes of the Armenian language, only 21 are represented in the general sample and subsequently in the test lists. Comparing the test lists and the Armenian language, the largest phoneme distribution differences were found in the phonemes [s], [n/ŋ] and [u], which are 9.1%, 8% and 7.6% respectively more frequently represented in the test lists; and phoneme [ɑ], which is represented 7.2% less. The frequencies of the other phonemes varied 0-4% between both distributions.

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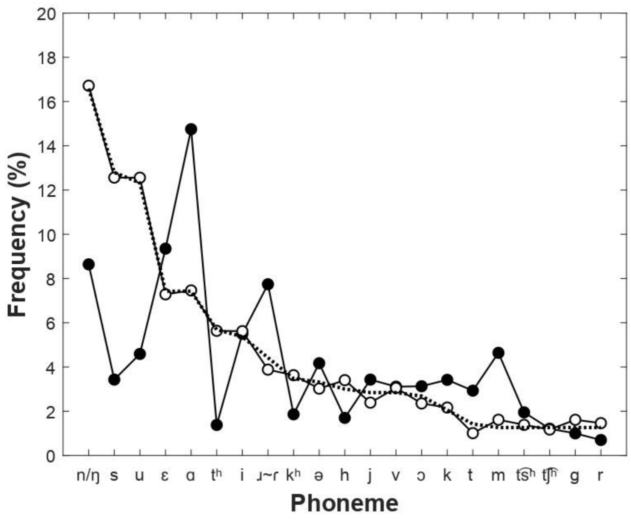

Figure 3. Phonemic structure of general sample (dotted line), test lists (solid line with open circles) and corpus (solid line with black circles).

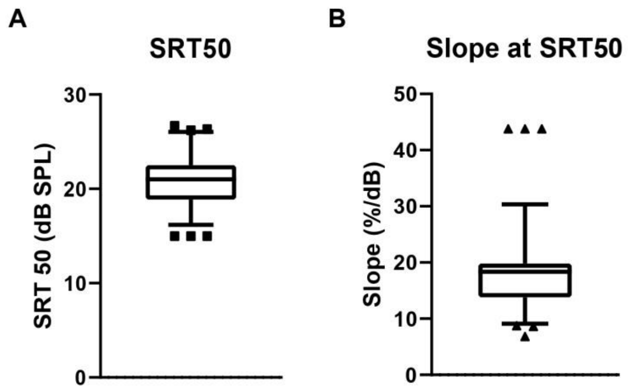

Figure 4. Distributions of A. SRT50 and B. the slopes at the SRT50 for all test items averaged across the subjects. Box plots show the median, 25 and 75 percentiles. Whiskers mark the the 5 and 95 percentiles.

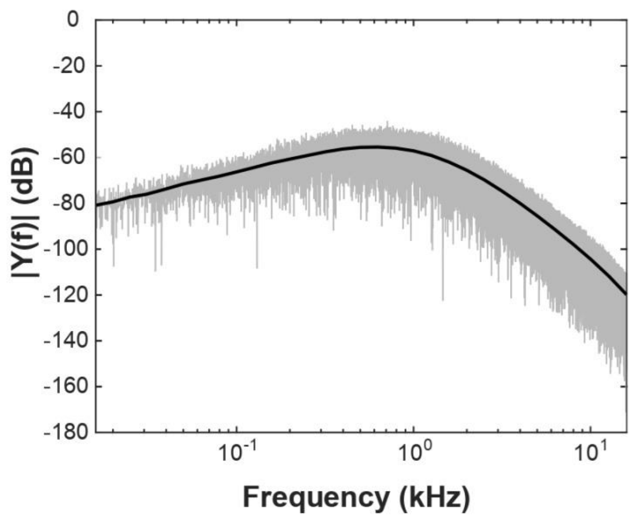

Figure 5. Frequency spectrum of the CCITT noise for calibration.

Figure 4 shows the SRT50 and the slope of the speech discrimination function for all test items as average across the subjects. The mean SRT50 across the subjects and test items was 20.8 dB SPL (SD=2.69 dB). The mean slope of the speech discrimination function was 17.9 %/dB (SD=6.8 %/dB). Both, the distributions of SRT50 and the slopes were not different from a normal distribution ($\chi^2(55)=15.35$, p=1). The resulting correction values for the final RMS scaling of the balanced test items were derived from the difference of the item specific SRT50 to the global mean SRT50 and limited to ±3 dB. *Figure* 5 shows the frequency spectrum of the calibration noise signal.

Discussion

The aim of this study was to develop, record and evaluate speech materials in line with internationally accepted criteria for SRT measurements in native Armenian speakers. Twenty lists of numerals based on the phonemic structure of Armenian numerals were developed based on a general sample. The results show equivalence between phonemic distributions of the test lists and the general sample. Therefore, the resulting test material is a phonemically homogeneous and representative sample of spoken Armenian language [40].

To form the so-called Khachatryan corpus, 10.000 character passages have been selected from literary, scientific, physics and math texts. No significant phoneme distribution differences between the text types were found for the vowels: the most frequent one is always [ɑ], followed by [ɛ]. Only the vowels [u] and [ə] have swapped ranks between the text types. Variations among consonants are larger, however, the sonants [n/ŋ], [m], and [ɹ~r] are among the most repeated phonemes and represent the first six ranks in the phoneme distribution table, followed by the consonants [s], [k] and [v], which ranks differ from each other by one or two places. The least frequent phoneme is [f], when it comes to the literary text, but it is more frequently encountered in mathematical texts.

Since not all the phonemes of the Armenian language are represented in the numerals and thus in the selected test items, the comparison of the phoneme distribution of the test lists with that of the Armenian language showed deviations. However, the comparison between the phoneme distributions (*Figure* 3) shows that the test lists represent the language corpus quite well.

The developed test is intended to measure the threshold of speech intelligibility, but not vocabulary or intelligence [43]. Test material for developing speech audiometric tests should meet the requirements of familiarity, phonetic dissimilarity, representative sample of speech sounds, and homogeneity with respect to audibility [43]. For SRT measurements, however, only familiarity and homogeneity of audibility were identified as most important [27]. The use of numerals is based on previous research and clinical reports showing the applicability of using digit stimuli for SRT measurements [44]. Digits are also preferred because of the highest familiarity and are homogeneity with respect to audibility [45]. Both requirements are also fulfilled by the present test material.

The results show a mean SRT of 20.8 dB SPL for the Armenian test items. This is in line with SRT measurements of other languages using numerals as test items [37]. Further, numerals demonstrate the steepest articulation function among speech audiometric stimuli [45]. The present results show a mean slope of 17.9 %/dB at the inflection point of the speech intelligibility

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functions (i.e., the SRT level), which is almost equal to that of the Oldenburg matrix test for test lists of German sentences [26].

Twenty test lists were selected to avoid redundancy if patients were tested repeatedly. The RMS level of the test items was balanced across all test items to assume equal SRT values across the test lists. The next steps will be the comparison of the speech intelligibility functions across the test lists in a larger cohort of normal hearing and hearing impaired native Armenian speaking subjects.

Conclusion

In conclusion, the developed test lists are a phonetically homogenous representation of the Armenian language and provide an appropriated base to clinically measure SRT in Armenian speaking listeners.

Acknowledgments

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Conflict of interest

The authors declare no conflicts of interest.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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