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Original Article

An Explanatory Research on the Development of the Speech Test Signal in Hearing-Aid Fitting

Eyyup KARA[1], Özgül AKIN ŞENKAL[2], Halide ÇETİN KARA[3], Züleyha Dilek GÜLMEZ[1], Seda AKDOĞAN[1], H. Murat YENER[3]

[1]Department of Audiology, İstanbul University-Cerrahpaşa, Faculty of Health Science, İstanbul, Turkey
[2]Department of Special Education, Çukurova University, Adana, Tukey
[3]Department of Ear-Nose-Throat, İstanbul University-Cerrahpaşa, Cerrahpaşa Faculty of Medicine, İstanbul, Turkey

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ABSTRACT

Objective: International Speech Test Signal is developed with voices in 6 different languages and used for the determination of output frequencies of hearing aids in the real-ear measurement. This study aims to standardize the International Speech Test Signal for Turkish.

Methods: The International Speech Test Signal passage was translated into Turkish; the resulting signal was arranged based on fundamental frequency, age, and gender characteristics, following the way the original signal was created. Patients with hearing loss were included. Following audiological tests, Real-Ear Aided Gain measurement was performed with the original International Speech Test Signal in the first step. The second step of the Real-Ear Aided Gain measurement was performed using International Speech Test Signal in Turkish. The gain values from both steps were compared statistically.

Results: Evaluation of the signal as a whole indicates that the inclusion of the Turkish signal does not cause any difference in terms of amplitude distribution. Real-aided gain data obtained from the original International Speech Test Signal were compared with that of the Turkish-added International Speech Test Signal.

Conclusion: Turkish can be added to the International Speech Test Signal that enables a more accurate fitting of hearing aids through the feedback of patients.

Keywords: Hearing aids, International Speech Test Signal, sensorineural hearing loss, REM signal, hearing aids fitting

Introduction

Every year, manufacturers introduce new products and technology upgrades in hearing-aid technology. Recently, significant progress has been made in hearing-aid technology over the last decade and user satisfaction rates did not improve as much. Among many others, one reason for this is the inadequate fitting of the hearing aid.[1] The most important mistake made in the fitting of hearing aids is skipping real-ear measurement and relying on manufacturers fitting algorithms.[2] Consequently, hearing-aid users express dissatisfaction because their fittings are not individualized to their language and not accurate fitting.[3] Real-Ear Measurement (REM) is performed to determine the gain of the hearing aid worn by the patient.

The Real-Ear Measurement process, which takes approximately 4 minutes, enables to determine of how much a hearing aid amplifies different loudness levels received by the ear and ensures uncomfortable loudness levels are not exceeded. Various signals are used as stimuli during REM. One of the prevalently used signals is International Speech Test Signal (ISTS).[4] International Speech Test Signal was developed in regard to the progress in hearing-aid technology; artificial signals used in REM lack fundamental frequencies and their harmonics which are intrinsic to speech. Also, artificial signals do not have natural speech properties like speech spectrum and modulation spectrum, and it is not possible to re-modulate these with artificial signals, thus leading to the development of ISTS with speech stimulus to be used in the REM.[4] International Speech Test Signal is an internationally valid stimulus, created with the reading of phonetically appropriate passage "The North Wind and the Sun" in American English, German, Arabic, Chinese, French, and Spanish, which are the most spoken languages in the world.[5] The signals were created by female speakers in different languages (Table 1). However, ISTS did not create in the Turkish language yet. Turkish is typologically an agglutinating language and has vowel and consonant harmony according to their structures. This means that all the vowels in a word must be of the same general

Corresponding author: Eyyup KARA, e-mail: eyup.kara@istanbul.edu.tr

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Table 1. Age and Fundamental Frequencies of the Speakers in ISTS

Language	*Age*	*Fundamental Frequency F_0 (Hz)*
Arabic	37	204
English	29	194
French	25	201
German	33	205
Chinese	26	208
Spanish	26	207

ISTS, International Speech Test Signal.

type (vowels produced at the front of the mouth or vowels produced at the back of the mouth). English does not have this feature. Therefore, ISTS in Turkish with a female voice might be used in hearing-aid fitting for patients with hearing impairment. Vowels are generally higher in intensity, longer in duration, and lower in frequency.[6] In speech perception, consonants are commonly thought to carry more information in sentence intelligibility than vowels.[7] The contribution of consonant versus vowel information to sentence intelligibility for young normal-hearing and elderly hearing-impaired listeners is essential in hearing-aid fitting.[7] It is quite easy to derive new words in Turkish.[8] There is no irregular verb and there is no suffix in the beginning and middle of the word in Turkish. According to a certain rule and order, constructive suffixes and inflectional suffixes are added to the end of the word. If both inflectional and inflectional suffixes are to be added to the end of a word, the inflectional suffix is added first and then the other suffix. In this respect, it differs from other languages. There are no vowels or consonants that come together at the beginning of words in Turkish. This feature is important in terms of speech discrimination.[9] Turkish has a regular front–back vowel harmony which dictates that all vowels within a word must be either in the front or back. If vowel harmony is used as a word segmentation cue, we expect its effect to arise in Turkish.[9] Therefore, ISTS in Turkish must be implemented in hearing-aid fitting.

The main reason for using the female voice is that it is located in the middle of the frequency of the male and child voice. It is generally referred for the fitting of hearing aids and cochlear implants users.[5] International Speech Test Signal is formed by recording the passage in 6 different languages, splitting the recording into segments, and randomly remixing them. The created signal encompasses all voiced and unvoiced components of normal speech. The elements of the voice should have fundamental frequency values and their appropriate harmonics.[5] Despite several exceptions to vowel harmony patterns existing in the Turkish language, vowel harmony is a highly active process whereby affix vowels obligatorily show alternation depending on the vowel of the host they attach to. As a result, an overwhelming majority of Turkish words, morphological simplex or simplex alike, are harmonic.[9] Turkish is an agglutinative language from the Turkic language family, spoken in Eastern Europe and Anatolia by more than 88 million people as of 2020. It is written in the Turkish alphabets are Latin-based one. This means it is very useful to develop ISTS in Turkish for potential hearing-aid users who speak Turkish.

Most of the systems used for evaluating hearing-aid amplification in the patient's ear consist of continuous or intermittent, usually monolingual (mostly English), speech signals. The primary aim of monolingual passage use in the clinic is to confirm the intelligibility of the speech while the patient wears the hearing aid, thus creating the opportunity to fine-tune the hearing aid according to the feedback from the patient.[8] Hearing-aid users experience many speech stimuli with varying spectra in daily life.[10] For this reason, it is an undeniable necessity to develop an acoustically and phonetically appropriate speech signal in the native language to measure speech intelligibility while the patient wears the hearing aid.[11] Our study has aimed to create ISTS in the Turkish language and used hearing-aid fitting in a clinical setting. International Speech Test Signal in the Turkish language may provide a more accurate hearing-aid fitting.

Methods

The study was approved by the local ethical committee and was conducted by following the standards of the local ethical committee of İstanbul University-Cerrahpaşa, Medical Faculty (Date: April 13, 2017, no: 83045809-604.01.02) and the Helsinki Declaration of 1975. Written informed consent was obtained from the patients. Verbal and written assent was also obtained from parents after a research assistant read aloud a short, University ethical committee approved script in a simple language to them. The script explained the study procedures and expectations (i.e., what to do in hearing-aid fitting), and patients were also allowed to ask questions.

This study included 100 patients (50 males and 50 females) between 18 and 65 years who applied to the İstanbul University-Cerrahpaşa, Faculty of Medicine Otorhinolaryngology outpatient clinic with cochlear hearing loss from June to July 2019. Initially, all patients were evaluated by an ear, nose, and throat specialist. Otoscopic examination of the patients showed no pathology in the middle ear and tympanic membrane. Audiologic evaluations and hearing-aid fitting have been done by a certified audiologist after otoscopic examination in the same session. The use of hearing aid was indicated because of audiological tests. Appropriate behind-the-ear hearing aids were selected for the first-time users considering the type, severity, and configuration of the hearing loss and their age and profession. Fine-tuning of the hearing aids was done based on their hearing needs via the fitting software of the hearing aids. New hearing tests and fittings were performed with current users of hearing aid who presented to our clinic due to changes in their hearing thresholds. Exclusion criteria were determined as multi-handicaps, outer or middle ear problems, retrocochlear pathology, presence of fluctuant hearing loss, speech discrimination score below 50%, and declining configuration of the audiogram in the lower frequencies. *Otometrics Aurical* (*Otometrics, Natus Medical ApS. Hørskætten 9, 2630 Taastrup, Denmark*) was used for REM. The patient was seated 1 m away from the speaker and facing 0° azimuth with ambient noise below 30 dBA. In the first step, real-ear-aided gain (REAG) measurement was performed with the current standard ISTS signal in the 250-6000 Hz range and at low-mid and high loudness levels (50-70-90 dB). Adjustments were made to the hearing aid based on the target curves calculated in REM. In the second step, the Turkish version of the ISTS signal, which was based on the numerical data (frequency range and loudness levels) applied in the first step, was used in REAG measurement, and adjustments were made to the hearing aid based on the target curves re-calculated in REM.

ISTS Adaptation in the Turkish Language

The passage "*The North Wind and the Sun*" was translated into Turkish and read 6 times by a female native speaker with natural intonation, vocal effort, and at a normal pace. The recordings were made using a Shure SM 58 directional microphone. The microphone was placed at an angle of about 45° below the mouth of the speakers at a distance of 20-30 cm. The paper sheet with the written story was placed in front of, and slightly above, the eyes of the speakers at a distance of about 50 cm. The recordings were sampled with a sampling frequency of 44 100 Hz and a resolution of 24 bits. The recordings took place in an office space, which was modified with absorbers and diffusers to get a reverberation time of 0.5 seconds at 500 Hz with a computer and the software CSL (*Computerized Speech Laboratory,* PENTAX Medical A Division of PENTAX of America, Inc. 3 Paragon Drive Montvale, New Jersey, 07645-1782 USA)). The duration of the passage in Turkish was measured as approximately 48 seconds. The pronunciation, intelligibility, and fundamental frequency (F_0) properties of the passage sample in Turkish were selected similar to those of the voices in the original recording.

Technically consistent with how the original signal was created in the software, the Turkish signal was split into segments of 500 and 100 msec, containing speech utterances and silent pauses, respectively. These segments were added to the original signal randomly, creating a new signal that consists of 7 languages including Turkish. To compare the compatibility of the new and original signals, *Adobe Audition* audio software (*Adobe, 345 Park Avenue San Jose, CA, USA*) was used for deriving spectrograms with phonemes energy intensity and loudness analysis graphs.

Statistical Analysis

Data were analyzed using Statistical Package for the Social Sciences 21.0 (IBM SPSS Corp., Armonk, NY, USA). According to Shapiro–Wilk normality test results, all the variables were not normally distributed ($P = .03$). Kruskal–Wallis and Mann–Whitney *U* tests were used to compare the mean scores of REAG data from both ISTS signals.

Results

The F0 of a Turkish female speaker (28 years of age) was 201 Hz who was reading the passage in Turkish ISTS. Similar results with different languages in ISTS were obtained in the F0 base (Table 2). Arrangement and integration of the recording into ISTS signal were done with the software. The spectrogram of the original ISTS and ISTS including the Turkish signal is shown in Figure 1a and Figure 1b. Spectrograms are graphs that demonstrate the energy content of the signals with intensity, frequency, and time components. The 2 signals are shown to have similar energy intensities according to the spectrograms.

Figures 2a and 2b show the amplitude distributions of ISTS signals. The original ISTS (Figure 2a) and Turkish-added ISTS (Figure 2b) have similar amplitude distributions ($P > .05$). Evaluation of the signal as a whole indicates that the inclusion of the Turkish signal does not cause any difference in terms of amplitude distribution ($P > .05$). Figures 3a and 3b demonstrate the aided gains in the decibel, obtained from hearing-aid fittings based on REM which was performed with the original ISTS and Turkish included ISTS, respectively.

Real-aided gain data obtained from the original ISTS were compared with that of Turkish-added ISTS. Table 2 showed the results for each frequency and amplitude. The acoustic characteristics of signals in Turkish did not change the acoustic characteristics of ISTS signals regarding F0 and dynamic range. No significant difference was observed as *P* was >.05 in all the results obtained at input signals 50 dB SPL, 70 dB SPL, and 90 dB SPL between 250 and 6000 Hz in both measurements (Table 3). It was observed that there was no significant difference between input signals50-70-90 dB SPL with REM in comparison to the hearing-aid target gain curves obtained with the original ISTS signal and the Turkish-added ISTS signal ($P > .05$) (Figure 3a and Figure 3b).

Table 2. Comparison of the ISTS Signal with the Turkish Language Added and the Original ISTS Signal

Parameters	Original ISTS	Turkish-Added ISTS
Peak amplitude (dB)	18.63	18.28
True peak amplitude (dB)	18.56	18.28
Total RMS amplitude (dB)	37.79	37.83
Maximum RMS amplitude (dB)	27.29	26.91
Minimum RMS amplitude (dB)	121.8	105.13
Avarage RMS amplitude (dB)	46.02	44.74
Dynamic range used (dB)	51.1	50.6
Loudness (dB)	35.23	35.76
Overall frequency (Hz)	208.5	242.38
All speakers F0 (Hz)	203	201

ISTS, International Speech Test Signal; F0, fundamental frequency; RMS, Root mean square.

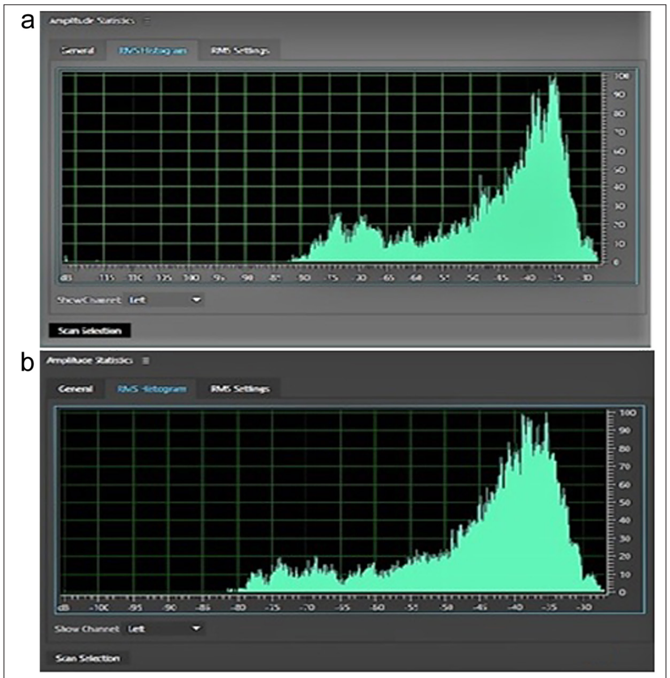


Figure 1. Spectrogram of ISTS (spectrogram of Turkish signal-added ISTS was shown in left. Red and yellow colours show intense energy parts, which are the voice signal itself. Dark colours indicate silent pauses with no energy). ISTS, International Speech Test Signal.

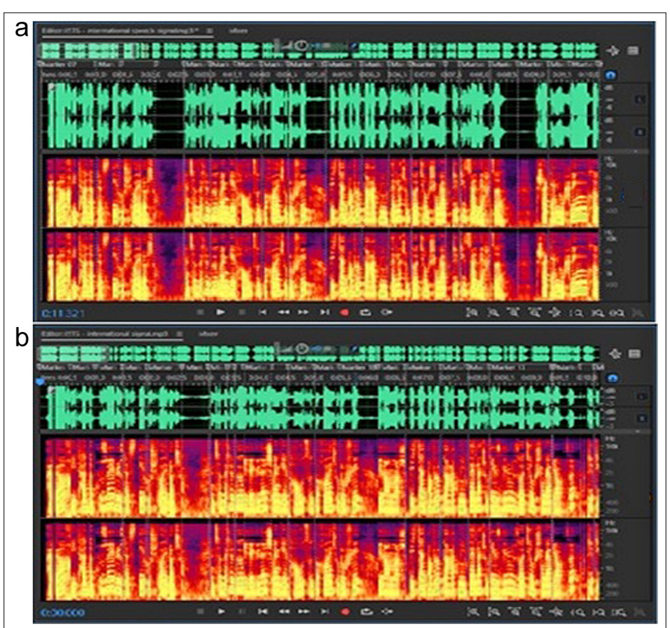
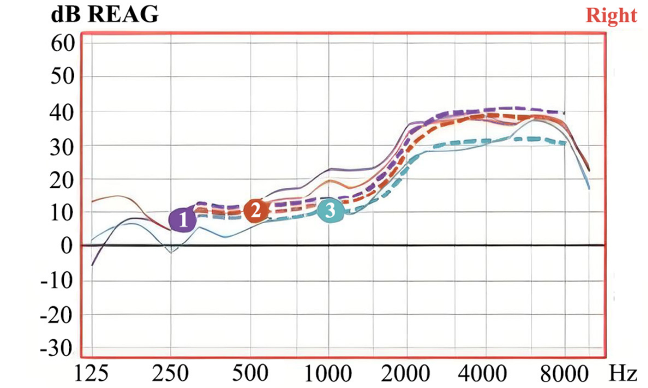


Figure 2. ISTS amplitude distribution (amplitude distribution of Turkish signal-added ISTS was shown on the left). ISTS, International Speech Test Signal.



Aided Gain Table Right

Right	250	500	750	1k	1.5k	2k	3k	4k	6k
Target 1	8	12	13	14	19	32	39	40	40
Curve 1	5	12	18	22	24	35	38	38	38
Target 2	6	10	11	13	17	28	36	39	38
Curve 2	5	11	14	19	21	33	37	37	38
Target 3	5	9	9	10	14	23	31	31	32
Curve 3	-2	6	9	12	15	25	29	31	36

Figure 3. REM performed with the original ISTS (REM that was performed with the included Turkish ISTS was shown on the left). ISTS, International Speech Test Signal; REM, real-ear measurement.

Discussion

International Speech Test Signal was not representative of many languages. Turkish is the most widely spoken fifth language in the world, with around 100 million speakers. Outside Turkey, significant smaller groups of speakers exist in Germany, Austria, Bulgaria, North Macedonia, Northern Cyprus, Greece, the Caucasus, and other parts of Europe and Central Asia. Therefore, the Turkish language has been added to ISTS and compared with the original ISTS. In a study, a speech test signal in Brazilian Portuguese that is electroacoustically similar to the international long-term average speech spectrum to use in real-ear measurements was developed for Brazilian Portuguese speakers.[7] A Brazilian Portuguese speech passage read by a female speaker was recorded using standardized equipment and procedures and compared to ISTS. The average difference between the new signal and ISTS and the deviation was determined as 3 dB in amplitude analyses of all frequencies measured during fitting (200-8000 Hz). Thus, it was concluded that this passage provided similar electroacoustic hearing evaluations to those expected from the ISTS passage. In this study, the average difference was found to be 1.28 dB as the result of amplitude analysis between the original ISTS and Turkish-added ISTS across the 250-6000 Hz frequency range. No significant difference was determined between the original ISTS and Turkish-added ISTS in this study. This finding demonstrates that there is no significant difference in acoustical characteristics between Turkish-added and original ISTS. Turkish differs from the acoustic-phonetic structure of other languages by the fact that the number of vowels is greater in Turkish than in other languages. Every Turkish syllable contains a carrier vowel.[8] This carrier vowel will change the spectral structure of the average F0 and the F0 average intensity of the passage, even though the original signal's characteristics are not affected by the Turkish added signal. Turkish-added ISTS provides an enriched sound to those expected from the original ISTS passage. It also indicates that Turkish-added sections of the signal have similar energy intensities according to the spectrograms based on phonemes and that amplitude analysis graphs also have a similar distribution with respect to the original ISTS. Despite the number of vowels and different vowel–consonant combinations of the Turkish-added ISTS, it did not cause a significant difference in the average spectral characteristics ($P > .05$). The data showed that Turkish can be added as the seventh language to the ISTS. The Turkish language has vowel harmony and extensive agglutination, which are important for speech perception (11). The acoustic-phonetic structure of Turkish is relatively different from the other 6 languages which are used in the existing ISTS. Eight vowel and consonant combinations in Turkish do not fit the cluster structure found in European languages,[8] as in European languages, words are formed with consonant-clustered syllables. This case reveals the acoustic-phonetic differences in ISTS signals.

The hearing-aid target output curves (input signals 50 dB SPL, 70 dB SPL, and 90 dB SPL; and frequency range 250-6000 Hz) were compared, and no significant differences were observed between Turkish and original ISTS output curves ($P > .05$). Although there is no significant difference between Turkish vowel combinations, the Turkish ISTS allows the hearing-aid fitting for Turkish speaking users in the expected formal way, due to the effect of these structures on speech discrimination (tense suffixes at the end of the word, belonging suffixes, reinforcement adjective suffixes, etc.).

They created ISTS in 2010 and there is not any similar study in this field except the one done in Brazil in 2013. There is no other explanatory study that includes the addition of a unique language to ISTS, which makes our study unique. Further studies in this area are needed with the focus on language-specific ISTS comparison studies while examining the hearing-aid fitting. In this study, we have not looked at large groups or age groups to specify ISTS. That part also needs to be addressed. It can be concluded that the speech signal developed by adding a Turkish passage to the original ISTS enables a more accurate fitting of hearing aids through the feedback of patients during REM and this speech signal can be regarded as an objective means for real-ear measurement of Turkish speaking patients both in Turkey and in other countries in the future.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Istanbul University. (Date: April 13, 2017, Approval No: 83045809-604.01.02)

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – E.K., Ö.A.Ş., S.A.; Design – E.K.; Supervision – E.K., Ö.A.Ş., H.Ç.K.; Materials – S.A., Z.D.G., H.M.Y.; Data Collection and/or

Table 3. The Results of Each Frequency and Amplitude.

	250 Hz	*500 Hz*	*750 Hz*	*1 kHz*	*1.5 kHz*	*2 kHz*	*3 kHz*	*4 kHz*	*6 kHz*
50 dB	0.732	0.761	0.762	0.569	0.341	0.649	0.732	0.76	0.94
70 dB	0.564	0.722	0.69	1	1	0.929	0.825	0.894	0.825
90 dB	0.689	0.823	0.595	0.859	0.658	0.825	0.757	0.791	0.755

Processing – S.A., Z.D.G., H.M.Y.; Analysis and/or Interpretation – E.K., H.M.Y.; Literature Review – H.Ç.K., S.A., Z.D.G.; Writing – E.K., Ö.A.Ş.; Critical Review – H.M.Y., Ö.A.Ş.

Declaration of Interests: The authors have no conflicts of interest to declare.

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