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Speech Audiometry: The Development of Lithuanian Bisyllabic Phonemically Balanced Word Lists for Evaluation of Speech Recognition

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Abstract: Background and Objectives: Speech audiometry employs standardized materials, typically in the language spoken by the target population. Language-specific nuances, including phonological features, influence speech perception and recognition. The material of speech audiometry tests for the assessment of word recognition comprises lists of words that are phonemically or phonetically balanced. As auditory perception is influenced by a variety of linguistic features, it is necessary to develop test materials for the listener's mother tongue. The objective of our study was to compose and evaluate new lists of Lithuanian words to assess speech recognition abilities. Materials and Methods: The main criteria for composing new lists of Lithuanian words included the syllable structure and frequency, the correlation between consonant and vowel phonemes, the frequency of specific vowel and consonant phonemes, word familiarity and rate. The words for the new lists were chosen from the *Frequency Dictionary of Written Lithuanian* according to the above criteria. Word recognition was assessed at different levels of presentations. The word list data were analyzed using a linear mixed-effect model for repeated measures. Results: Two hundred bisyllabic words were selected and organized into four lists. The results showed no statistically significant difference between the four sets of words. The interaction of the word list and presentation level was not statistically significant. Conclusions: Monaural performance functions indicated good inter-list reliability with no significant differences between the word recognition scores on the different bisyllabic word lists at each of the tested intensities. The word lists developed are equivalent, reliable and can be valuable for assessing speech recognition in a variety of conditions, including diagnosis, hearing rehabilitation and research.

Keywords: speech; recognition; audiometry; phonetic; bisyllabic word

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1. Introduction

Speech audiometry is a part of the basic audiologic evaluation, and it helps to evaluate a person's capability to perceive and understand certain forms of linguistic stimuli [1]. In addition to diagnosing hearing loss, speech audiometry is also used to monitor hearing aids and cochlear implants, to assess auditory processing disorders and to evaluate candidates for auditory rehabilitation programs. The most commonly used speech audiometry method is the word recognition score (WRS). This testing assesses a person's capability to comprehend words presented at different levels above their speech recognition threshold, providing valuable insights into their hearing abilities in everyday environments. The material for the word recognition test consists of sets of words that are phonemically or phonetically balanced (PB words). The lists of PB word lists are designed to approximate

the frequency of the various speech sounds that normally occur in the language. Many sets containing monosyllabic words are available in English; among them are the word lists of the Central Institute of Deaf (CID W-22) and of Northwestern University (NU-6) [2]. The criteria of the selection of words for word recognition tests include an equivalent average difficulty and equivalent phonetic composition between the lists, an equivalent average difficulty within the lists and familiarity of the words [3]. Given that linguistic aspects impact how we perceive sound, it is crucial that test materials are written in the language spoken by the listeners in order to ensure the tests are accurate and efficient [4]. Although the basic principles of test development for speech audiometry remain the same across languages, the specific test materials differ due to phonetic characteristics and cultural contexts. A variety of word lists have been created in many different languages based on the specific features of the given language, such as Greek, Turkish, Polish, Korean, Mandarin, Tamil, Cantonese and Arabic [5–18].

Lithuanian belongs to the Baltic branch of the Indo-European language family. Lithuanian is one of the two living Baltic languages, along with Latvian, and forms the eastern branch of the Baltic languages family. It is also one of the 24 official languages of the European Union. Today, Lithuanian is spoken by almost 4.5 million people all over the world, with the majority of them (about 3 million) living in Lithuania. The largest Lithuanian diasporas are concentrated in the United States of America, the United Kingdom, Norway, Germany and Denmark. The Lithuanian language has two dialects, which in turn are classified into six sub-dialects and 12 speeches [19]. The most important features of the Lithuanian phonological system are the free distinctive stress (i.e., the stress distinguishes words and their forms); the tone system (i.e., Lithuanian is a tonal language and has two contrasting intonations—rising and falling—distinguishing different meanings); and the vowels in the vowel system of the standard Lithuanian language feature two phonological lengths (i.e., short and long vowels are independent phonemes and their contrast plays the role of distinction). The Lithuanian language is a flexional language where grammatical relations between words are expressed by inflections [20]. A reduction in endings is not common to the standard Lithuanian language; vowels and consonants are retained in the endings, so two-syllable words do not get shortened, except in certain dialects. Most words in standard Lithuanian have two, three or four syllables. There are only a few monosyllabic nouns or verbs in their infinitive form in the Lithuanian language.

Word lists for speech audiometry tests in the Lithuanian language were first developed several decades ago [21]. Polysyllabic words from those lists were both used for the speech recognition threshold (SRT) and for the WRS measurement. The set of words consisted of 20 items per list. The choice and the specific applicability of the words raised certain concerns: Although the frequency ratios between vowel, diphthong and consonant phonemes have been assessed, neither specific phonemes nor their frequency ratios have been analyzed. The interrelation between two-syllable, three-syllable and four-syllable words has been defined; however, neither the structure nor the type of syllables has been analyzed. Several words included in the lists have already become historicisms or have gained a negative connotation in the current context or are no longer or less frequently used in modern speech. Due to the different principles, basing the formation of the lists, it was difficult to compare the results obtained by the current speech audiometry tests to those presented in international studies.

The objective of this study was to compose and evaluate new sets of words in the Lithuanian language for the assessment of speech recognition, taking into account the phonological patterns of the modern standard Lithuanian language.

2. Materials and Methods

2.1. Test Material

Based on the linguistic characteristics and due to the fact that the Lithuanian language has an inadequate number of monosyllables, bisyllabic words were chosen for the selection of the list items. The list of phonemically balanced bisyllabic words is based on the following

criteria: the occurrence rate of particular vowel and consonant sounds, the relationship between specific phonemes, the structure and occurrence rate of the syllable types in Lithuanian and the relationship between them. The most recent studies by Lithuanian linguists on the phonology-level statistical structure of the Lithuanian language were analyzed keeping in mind the mentioned criteria [22]. The analysis of the specific empirical material of the studies of the Lithuanian language identified the most frequently occurring syllable patterns (Table 1).

Table 1. The structural patterns of Lithuanian bisyllabic words, selected for speech material (C refers to any consonant; R—consonants *r*, *l*, *m* and *n*; $\overline{\text{V}}$—any long vowel; and $\breve{\text{V}}$—any short vowel).

1 Model	2 Model	3 Model
C $\overline{\text{V}}$—C $\breve{\text{V}}$	C $\overline{\text{V}}$—C $\breve{\text{V}}$ C	CVR—C $\breve{\text{V}}$
C $\breve{\text{V}}$—C $\overline{\text{V}}$	C $\breve{\text{V}}$—C $\overline{\text{V}}$ C	CVR—C $\breve{\text{V}}$ C
C $\breve{\text{V}}$—C $\breve{\text{V}}$	C $\breve{\text{V}}$—C $\breve{\text{V}}$ C	C $\breve{\text{V}}$ C—CVR

Words matching the structural patterns of phonemically balanced words identified on the basis of the frequency rates of phonemes and syllables were chosen from the *Frequency Lexicon of Modern Written Lithuanian* language depending on the frequency of the words in the corpus [23]. The words that were considered to be unfamiliar, culturally insensitive or with negative implications were excluded from the list. When choosing the words, the fact that the Lithuanian language has free distinctive stress was also considered. Therefore, both types of words, i.e., with a stress on the first or the second syllable for each pattern, were included in the list. The chosen words represent either rising or falling tones in the case of both long and short vowels.

2.2. Recordings of Words

The recording was performed in a large sound-treated double-walled booth using the condenser microphone (model AKG C414 XLS (AKG, Vienna, Austria)) functioning in the cardioid mode. The chosen words were read out by a native Lithuanian male professional speaker in a natural intonation, keeping approximately the same loudness level and distance from the microphone. During the recording session, each word was recorded at least three times until the jury consisting of an audiologist and a linguist agreed that the vocal quality, pronunciation and accent were appropriate. The best version of each word was selected for inclusion into the speech audiometry test set. The microphone signal was pre-amplified and converted into the digital domain at the sampling frequency rate of 44.1 kHz and a 32-bit resolution. After the processing, the signals were exported to the computer hard disc using the Cockos Reaper v.5.2 audio editor software and then transferred to a compact audio disc using the Steinberg's Wavelab v.7.2 audio editor. A 4 s interval separated the presentation of each word. The 1000 Hz calibration tone of 60 s duration was synthesized and inserted at the beginning of the recording. The intensity of each recorded word was digitally adjusted to yield the same average Root Mean Square (RMS) power as that of a 1000 Hz calibration tone.

2.3. Participants

A total of 60 individuals (34 females and 26 males) participated in the testing of the list equivalence with the age of the participants ranging from 18 to 25 years, which is an average of 22.35 years. The description of the study participants is shown in Table 2.

All the participants of the study were native Lithuanian speakers. Their pure-tone air conduction thresholds were less than 10 dB HL at all octave frequencies from 250 to 8000 Hz (ANSI S3.6-1996; ASHA, 1990) [24,25]. All the subjects had static acoustic admittance between 0.3 and 1.4 mmhos, with the peak pressures between −100 and +50 daPa, and no medical history of ear-related problems were reported.

Table 2. Characteristics of study participants.

Characteristics of Study Participants (N—60)		
Gender	Female	34 (56.7%)
	Male	26 (43.3%)
Age, average ± SD	22.35 ± 5.3	
PTA, dB HL Average ± SD	5.43 ± 1.4	
Test ear	Right	32 (53.3%)
	Left	28 (46.7%)

2.4. Procedure

The study was carried out at the Department of Ear, Nose and Throat diseases at Vilnius University Hospital Santaros Clinics. Each study participant underwent an audiological assessment by otoscopy, impedance audiometry and pure-tone audiometry. The examination of the external ear canal and tympanic membrane was performed by otoscope. Tympanometry was performed with a Homoth impedance audiometer with a probe-tone frequency of 226 Hz. The audiological tests were performed in a double-walled sound-treated booth using a calibrated clinical audiometer (Interacoustics AC40, Interacoustics, Middelfart, Denmark) meeting the ANSI S3.6-1996 standards. Pure-tone audiometry was carried out at frequencies of 125, 250, 500, 1000, 2000, 4000 and 8000 Hz using both air and bone conduction. The pure-tone stimuli were presented via TDH-39 headphones. The speech stimuli were routed from a CD player (Panasonic DVD-S42, Panasonic, Osaka, Japan) to the clinical audiometer and delivered to the participants via TDH-39 headphones. Prior to each test session, the input of the audiometer was calibrated to a 0 volume unit (VU) using the 1000 Hz calibration tone. The assessment of the WRSs for each of the four 50-word lists was performed at different presentation levels ranging from 0 dB HL to 40 dB HL in 5 dB increments in quiet. The words were presented randomly to each participant monaurally, to either the left or the right ear randomly. The test ear was counterbalanced for the male and female subjects. The WRS was assessed by the percentage of correctly repeated words. The data were statistically analyzed by using Statistical Analysis System software SAS® Studio 9.4. A p value < 0.05 is regarded as statistically significant.

This study was approved by the Vilnius Regional Biomedical Research Ethics Committee of Lithuania. The participants signed an informed consent form at the beginning of this study.

3. Results

A total of 200 bisyllabic phonemically balanced words were selected and organized into four lists, with 50 words each. The words for every 50-item list were grouped considering an equal distribution of the Lithuanian consonant and vowel phonemes, syllable pattern and syllable stress. The words in the lists represent different parts of the language—nouns, verbs, adjectives and numerals. Both types of words, i.e., with a stress on the first or the second syllable, are included in the list. The consonant (C)–vowel (V) ratio in a syllable is 55.66% to 44.34% and there are two dominant types of syllables, CV (60.3%) and CVC (23.87%), in the developed set of words. In total, 60 individuals, divided into four equal groups, participated in the assessment of the WRSs for the different sets of 50 words (Figure 1).

The average percentage of the word recognition scores obtained at 40 dB HL was 99.9% of the word lists developed (List 1—100%, List 2—99.7%, List 3—99.9% and List 4—99.9%). The average percentage of correct results and standard deviations for the recognition of monosyllabic words from the four two-voice word lists are summarized in Table 3.

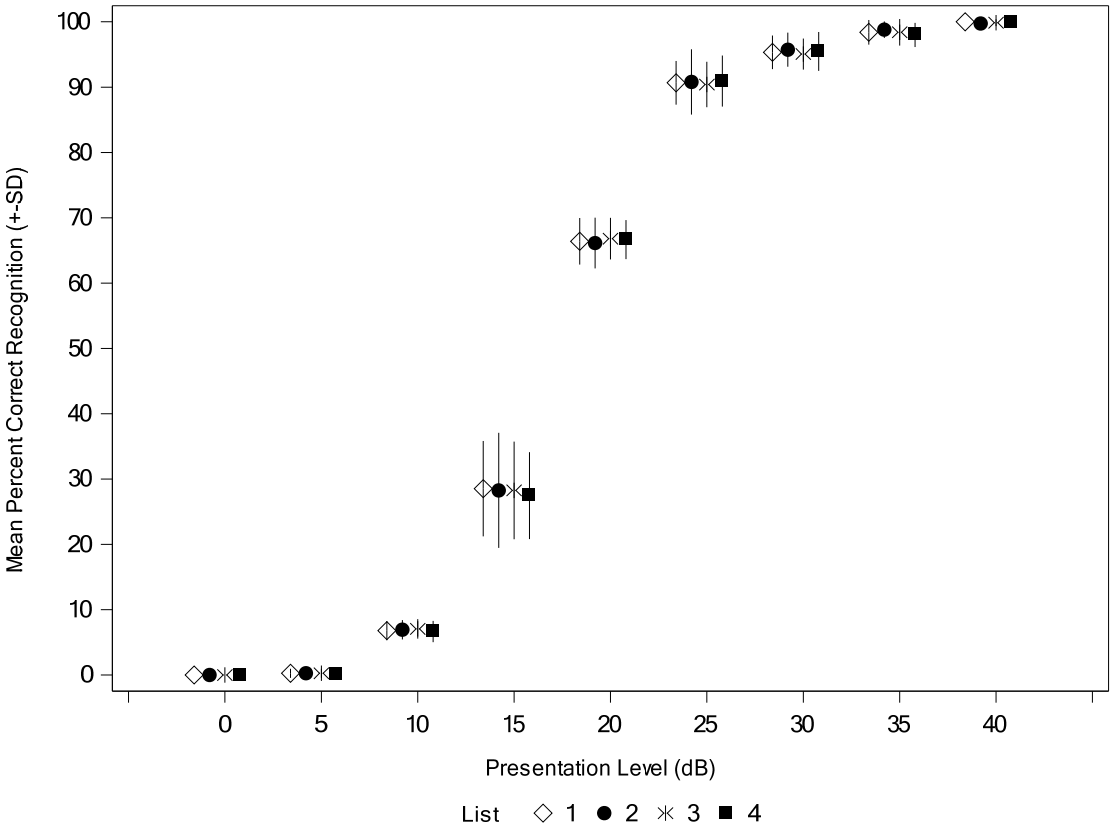

Figure 1. Mean word recognition scores and standard deviations at different presentation levels of four bisyllabic word lists.

Table 3. Mean percent of the monaural correct scores and standard deviations (SD) for the four 50-item lists ($p > 0.05$).

	0 dB	5 dB	10 dB	15 dB	20 dB	25 dB	30 dB	35 dB	40 dB
	Mean (%) (SD)	Mean (%) (SD)	Mean (%) (SD)	Mean (%) (SD)	Mean (%) (SD)	Mean (%) (SD)	Mean (%) (SD)	Mean (%) (SD)	Mean (%) (SD)
List 1	0 (0)	0.3 (0.7)	6.8 (1.47)	28.5 (7.31)	66.4 (3.56)	90.7 (3.35)	95.3 (2.58)	98.4 (1.88)	100 (0)
List 2	0 (0)	0.3 (0.7)	6.9 (1.49)	28.3 (8.81)	66.1 (3.89)	90.8 (5.01)	95.7 (2.6)	98.8 (1.26)	99.7 (0.7)
List 3	0 (0)	0.3 (0.7)	7.1 (1.49)	28.3 (7.48)	66.8 (3.19)	90.4 (3.48)	95.1 (2.37)	98.4 (2.03)	99.9 (0.52)
List 4	0 (0)	0.1 (0.52)	6.7 (1.63)	27.5 (6.65)	66.7 (2.99)	90.9 (3.92)	95.5 (2.97)	98.0 (1.85)	99.9 (0.52)
General	0 (0)	0.2 (0.65)	6.9 (1.49)	28.1 (7.42)	66.5 (3.35)	90.7 (3.89)	95.4 (2.59)	98.4 (1.76)	99.9 (0.5)

The data of the word lists were analyzed using the statistical model known as a linear mixed-effect model for repeated measures (MMRMs). The model for this analysis included the fixed and categorical effects of the word list, presentation level and their interaction. Subject dependence was modelled by an unstructured covariance matrix. The MMRM analysis did not reveal any statistically significant difference among any of the four bisyllabic phonemically balanced word sets (F [3.56] = 0.03 and $p = 0.9940$); meanwhile, the assessment of word recognition revealed a statistically significant difference at various presentation levels (F [7.56] = 121,687 and $p < 0.0001$). The interaction of the word list and presentation level was not statistically significant (F [21.56] = 0.28 and $p = 0.9990$).

The slopes of the mean functions were calculated using the following methods: (1) the instantaneous slope computed from the first derivative of the orthogonal polynomial used to fit each set of data, (2) the traditional linear slope that assumes a linear relation between the 20 percent and 80 percent correct points and is calculated simply as $\Delta y/\Delta x$ and (3) the average slope obtained by averaging the instantaneous slopes at 10 percent intervals from

the 20 percent to 80 percent correct points. The best-fit, third-degree polynomials for the four word lists are as follows: List 1, y = −0.972390572 + (−1.785525092)x + 0.373383357 × 2 + (−0.006714254) × 3; List 2, y = −0.835016835 + (−1.862542889)x + 0.378820587 × 2 + (−0.006805836) × 3; List 3, y = −0.993939394 + (−1.755363155)x + 0.371220779 × 2 + (−0.006680135) × 3; and List 4, y = −0.914478114 + (−1.879390733)x + 0.379667148 × 2 + (−0.006818406) × 3. The instantaneous slopes of the List 1 function range from 4.29 percent/dB at 20 percent correct to 4.49 percent/dB at 80 percent correct. The 5.15 percent/dB instantaneous slope at 50 percent is steeper than the 4.9 percent/dB linear slope, which is quite close to an average slope. The instantaneous slopes of List 2, List 3 and List 4 are similar to the slopes of List 1. The instantaneous slopes at 50 percent are steeper than the corresponding linear slopes for all the lists, while a similar steepness of the linear and average slopes is observed (Table 4).

Table 4. Mean performance of Lithuanian bisyllabic 50-item lists.

	The Instantaneous Slopes (%/dB)			Linear Slope 20–80 Percent (%/dB)	Average Slope (%/dB)
	20 Percent	50 Percent	80 Percent		
List 1	4.29	5.15	4.49	4.90	4.82
List 2	4.32	5.17	4.50	4.92	4.84
List 3	4.27	5.10	4.38	4.84	4.76
List 4	4.33	5.19	4.53	4.93	4.86

4. Discussion

Speech audiometry serves as a fundamental instrument in audiological assessment, aiding in the diagnosis and rehabilitation of individuals with hearing impairment. While pure-tone audiometry helps to estimate the softest sounds audible to a person, speech audiometry helps to evaluate an individual's capacity for perceiving and understanding speech. Speech audiometry determines patients' auditory ability using word lists that typify the everyday listening experience. Speech audiometry employs standardized materials, typically in the language spoken by the target population. Language-specific nuances, including phonological features, influence speech perception and recognition. The linguistic barriers represent a challenge when using speech materials different than the listener's native language. The necessity to develop speech audiometry test materials in native languages is essential in order to obtain valid speech recognition test results. For this purpose, speech tests have been constructed in various languages based on specific linguistic features. Word lists for speech audiometry tests in the Lithuanian language were first developed more than 40 years ago. Polysyllabic words from those lists were both used for the speech recognition threshold and for the WRS measurement. The set of words consisted of 20 items per list. Several words included in the lists have already become historicisms or have gained a negative connotation in the current context. The absence of standardized materials in the Lithuanian language presented a significant challenge in accurately assessing speech perception abilities among Lithuanian-speaking individuals. The aim of this present study was to compose a set of Lithuanian word lists for word recognition testing.

In order to affirm the validity and reliability of speech tests, the principle of phonemic balance (PB) has been used for many years in the development of speech material [4]. Word lists are considered to be phonemically balanced when different phonemes occur in the test material at the same relative frequency as they do in the language. This ensures that the test adequately samples the phonetic inventory of the language and provides a comprehensive assessment of the listener's phonetic discrimination abilities. English word lists, like PB-50, CID W-22 and NU-6, have been designed on the basis of the phonemic balance principle. Though there is also a converse estimation, as described by Martin et al. [24], that speech discrimination scores do not seem to be affected by whether the word list has

phonemic balance or not, PB has been chosen as the linguistic criterion in the development of Lithuanian speech material.

Egan (1948) has revealed the relation between the number of sounds in a word and the ability to recognize that word [3]. The more phonemes comprising the word, the easier the word is identified. Therefore, monosyllabic words are widely used in speech audiometry tests. In our study, bisyllabic words have been selected for the list items, because due to linguistic peculiarity there is an inadequate number of monosyllables in the Lithuanian language. The statistical analysis of the Lithuanian language has revealed that two-syllable, three-syllable and four-syllable words dominate in the standard Lithuanian language. Data taken from Lithuanian linguistic studies indicate that one word in the standard Lithuanian language consists of an average of 2.89 syllables. As the analysis of the reference sources shows, there are clearly two prevalent types of syllables in the Lithuanian language: CV (54.66%) and CVC (24.03%) [22]. On a syllable level, one syllable contains an average of 2.4 phonemes. The consonant–vowel ratio in a syllable, as assessed in the study by Kazlauskiene and Raskinis, is 54.5% to 45.5% [26]. The results of our study indicate that the syllables in the developed set of word lists characteristically have a consonant–vowel distribution of 55.66% to 44.34%, with two main syllable patterns prevailing, CV (60.3%) and CVC (23.87%), that generally match the data described by Lithuanian linguists. Other important principles in designing speech test materials are the familiarity of test items and the number of test items [27,28]. Cultural factors influence word familiarity, as certain words may be specific to particular cultures or contexts. Test materials that incorporate culturally relevant vocabulary are more likely to resonate with the listener and enhance their comprehension and performance on speech perception tests. Assuming that word familiarity is basically defined by a word's frequency of occurrence within the language, words for the Lithuanian speech material have been selected from the *Frequency Dictionary of Modern Written Lithuanian*, which is based on the 1 million words of the morphologically annotated corpus. The choice of words has been based on the frequency of words in the dictionary. The words that have been considered to be unfamiliar, culturally insensitive or with negative implications have not been included in the word lists. Only the most frequently used and familiar words have been included in the set of words.

Typically, 50-item word lists are adjusted in word recognition tests [2]. The inclusion of 50 items increases the reliability of word recognition scores [27]. Nevertheless, audiologists commonly use 25-item word lists to decrease the test time and mitigate the fatigue effect for participants. According to the literature, the percentage of respondents routinely using full 50-item test lists is decreasing considerably. Martin and Morris's (1989) survey has shown that 5.9% of respondents presented 50 words to all patients, 56.9%—25 words—to all patients and 24.8% presented 25 words when the first 25 responses have been correct [29]. In the recent study by Durankaya et al., a $\times 2$ test has been used to evaluate the inter-list equivalence among six 25-item word lists and three 50-item word lists. The percentage of correct recognition at 12 different presentation levels has not shown significant differences among the lists. The test has indicated the inter-list equivalence in both 25-item and 50-item word lists [6].

According to our study, the percentage of word recognition scores obtained at 40 dB HL is around 99% for the developed word lists. Similar results can also be found in the literature. In their study, Ullrich and Grimm (1976) have shown that individuals with normal hearing sensitivity reach a maximum score of about 99.7% at the most comfortable hearing level [30]. Beattie and colleagues have assessed the speech discrimination score of approximately 95% at 32 dB for individuals with normal hearing sensitivity upon administration of CID W-22 and NU-6 [31]. The results of our study indicate strong inter-list reliability with no significant differences ($p > 0.05$) between the main word recognition scores on the different lists at each of the tested intensities.

The estimation is that the more homogenous the psychometric characteristics of the individual items are, the steeper the slope of the mean psychometric function [32]. The psychometric function average slopes for the developed Lithuanian bisyllabic word lists

range from 4.76%/dB to 4.86%/dB. Coincidentally, these parameters are close to those obtained for English word materials. The mean slope of monosyllabic English words has been determined as 4.8%/dB for CID W-22 and 4.4%/dB for NU-6 word lists [33]. Beattie et al. have estimated the mean slope of 4.6%/dB for the CID W-22 word lists and 4.2%/dB for the NU-6 word lists [31]. The study by Heckendorf et al. has shown that the slope for the CID W-22 materials is 3.1%/dB [34]. The diversity in the psychometric function slope values may appear due to differences in the word length and specific linguistic traits. These variations are reported to range from a shallow slope of 1%/dB to as steep as 44%/dB [35].

5. Conclusions

The objective of the present study was to compose and evaluate new sets of words in the Lithuanian language for speech recognition assessment. Four word lists of 50 phonemically balanced bisyllabic words have been developed, taking into account word familiarity and word frequency, as well as the phonological characteristics of standard Lithuanian. The newly developed word lists for speech audiometry reflect the current Lithuanian language use and can be valuable for a more culturally and linguistically appropriate assessment of the hearing abilities of Lithuanian language users. The data of our research show that the composed lists of Lithuanian bisyllabic words are reliable, equivalent and can be valuable in assessing speech recognition in various conditions, including diagnosis, hearing rehabilitation and research.

As for future directions, we intend to continue our research with subjects of different ages and different types of ear pathology and hearing impairment.

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