Word Selection in the Slovenian Sentence Matrix Test for Speech Audiometry

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Abstract

In this paper we present the word selection process in the Slovenian matrix sentence test for speech intelligibility measurements. We focus on the phonemic distribution in the test, which should be approximated as closely as possible to the distribution in the language. We establish phonemic distribution for Slovenian by combining the orthographic distribution in the corpus ccKress and the phonetic distribution in Mihelič (2006). As a result, a phonemically balanced matrix test is proposed for Slovenian.

1. Background and Research Goals

Speech audiometry is one of the standard methods used to diagnose the type of hearing loss and to assess the communication function of the patient by determining the level of the patient's ability to understand and repeat words or sentences presented to him or her in a hearing test. For this purpose, the adaptation of the Freiburg Monosyllabic Word Test and the Freiburg Number Test are used in Slovenia. The Slovenian version was developed in Pompe (1968) and was then revised by Marvin et al. (2016).

While word tests are important diagnostic tools, sentence tests better reflect everyday communication and have proven to be highly useful and precise measurement tools in many languages. In general, two types of such tests are used; those using meaningful, everyday sentences with a variable grammatical structure (e.g. Plomp & Mimpen, 1979 and subsequent work) and sentence tests with a matrix structure, in which the syntax is fixed, but the combination of words is unpredictable (Hagerman, 1982; Wagener, 1999a, b, c; Ozimek et al., 2010; Hochmuth et al., 2012; Warzybok et al., 2015 among others). At present, there are no standard sentence tests of any kind available for Slovenian.

In this paper we present the word selection process for the sentence test with a matrix structure that we develop for Slovenian. The matrix test will be used for a more accurate assessment of hearing in people with a hearing disorder, for assessing the understanding of speech in people with central hearing disorders and comprehension disorders, for assessing cognitive abilities, for assessing the improvement of speech comprehension in patients using various removable and implanted mechanical and electronic hearing aids and in patients with disturbing tinnitus (hearing sounds in the ears or the head without any real sound inside or outside the body, Jagoda et al. 2018)). In creating the test, we follow the guidelines by International Collegium of Rehabilitative Audiology (ICRA), (Akeroyd et al., 2015). The guidelines complement the standard ISO 8253-3:2012 (Acoustics - Audiometric test methods - Part 3: Speech Audiometry) by providing the necessary steps needed to create the matrix test in any given language. The ICRA guidelines require that the matrix test should approximate the phonemic distribution of the underlying language as closely as possible. To our knowledge, the phonemic distribution of Slovenian has not been thoroughly analysed, so we derive it from the data on the letter distribution based on the corpus ccKres (see Erjavec and Logar Berginc, 2012; Logar Berginc and Krek, 2012; Logar Berginc et al., 2012 for more information on the corpus) in combination with the data on the phonetic distribution that is available in Mihelič (2006).

The paper is organized as follows. In Section 2 we describe the general construction of the test, in Section 3 we focus on the part in the test that involves word selection for the sentence construction. In Section 4 we present the word selection for the Slovenian matrix test.

2. General Guidelines for Matrix Test Construction

The matrix test was originally proposed for Swedish by Hagerman (1982). A modified version (Wagener et al., 1999a, b, c) is currently available in 14 languages (e.g. English, Dutch, German, French, Turkish and others), among them only in two Slavic languages (Polish and Russian). The test consists of five-word long sentences, each of which has the same syntax of the form Name-Verb-Numeral-Adjective-Noun, but whose semantic content is unpredictable (e.g. "Thomas wins eight red shoes"). The base matrix consists of 50 words, 10 for each of the five word positions. Each sentence is a random walk through the matrix and sentences are further grouped

into test lists of ten sentences in such a way that each list contains exactly one appearance of each of the 50 words in the base matrix.

The sentences are then recorded in such a way that all combinations of two consecutive words are included (this requires the recording of at least 100 sentences).[1] The recorded sentences are cut into single words by preserving the coarticulation at the end of the cut word to the required consecutive word, but truncating the coarticulation at the word beginning. The test sentences are then resythesized by combining words with appropriate transitions and supplied with masking noise. Finally, the test protocol includes the optimization and evaluation of the recorded material. The individual's speech recognition threshold is determined by an adaptive tracking procedure using one, two or three whole test lists.

3. Slovenian Matrix Test

3.1. Sentence Structure and Word Selection

In this section we describe the process of gathering the linguistic material in the base matrix, which consists of 50 words, 10 for each of the five word positions in the sentence of the form Name-Verb-Numeral-Adjective-Noun. The selected material has to fulfil several criteria.

To begin with, the test should contain five female and five male names. Next, only highly frequent words should be chosen; we establish that by referring to the GigaFida language corpus for Slovenian (see Erjavec and Logar Berginc, 2012; Logar Berginc and Krek, 2012; Logar Berginc et al., 2012 for more information on the corpus). We make sure that words and the combinations of words that are potentially offensive are not included in this list. Also, certain repetitive combinations (e.g. *veliko velikih kamnov* "many big stones") or similar names (*Jana*, *Jasna*) are avoided.

Next, all possible sentences that can be assembled by combining the words in the matrix have to be grammatically correct and semantically unpredictable. In matrix tests for Germanic languages, the past tense forms are generally used, while in the existing matrix tests for Slavic languages the present and the future tense forms are used. Using a verb in the past or future tense in Slovenian would require a special syntactic position for the copula, which is not included in the standard matrix test. Also, in the past tense forms or the future tense forms in Slovenian, the copula *biti* "be" is marked for number and person, while the *l*-participle is marked for gender and number. The use of these two tenses would thus result into a great number of ungrammatical combinations in cases where the gender of the participle does not agree with the gender of the subject (e.g. "*Jana je *kupil* tri velike škatle"). Therefore, only verbs in the present tense can be chosen to fill the verb position in the Slovenian matrix test (e.g. "Jana *kupi* tri velike škatle").

The selection of numerals has to be adapted to the properties of the Slovenian language. Only the numerals from five on are used in the test, as these uniformly require the following adjective and noun in the genitive plural form (e.g. "Jana kupi pet/šest/sedem/osem... *velikih škatel*"). The numerals from 1-4 are replaced by quantifier expressions that require the genitive plural form of the following adjective and noun, such as *malo* "few", *nekaj* "some", etc. (e.g. *Jana kupi malo/nekaj velikih škatel* "Jana buys few/some big boxes").

The number of syllables within each word group has to be balanced; we decide to select disyllabic words and only exceptionally monosyllabic or trisyllabic words (e.g. for reasons relating to phonemic balance).

Finally, a requirement for matrix tests is that the phonemic distribution of the underlying language should be approximated as closely as possible by the matrix test. As the phonemic distribution of Slovenian has not been established, the requirement in question demands our special attention and is dealt with in detail in Sections 3.2. to 3.4.

3.2. Relations Between Phonemes, Allophones and Letters in Slovenian

Before turning to the issue of phonemic balance, we briefly explain the notions of phoneme and allophone and their relation to the letters in the Slovenian alphabet. A phoneme is standardly defined as the smallest sound unit that can be segmented from the acoustic flow of speech and which functions as a semantically distinctive unit. If a sound unit is replaced by another sound unit in a word and the two words have a different meaning, we classify the two differentiating sounds as phonemes, e.g. in the English pair *pet – bet*, /p/ and /b/ are phonemes. Phonemes are abstract units, each phoneme representing a class of phonetically similar sound variants that are called allophones. An allophone is standardly defined as a concretely realized variant of a phoneme and is dependent on the phonological environment. For example, in English, the phoneme /p/ has an aspirated variant [p^h] at the beginning of the syllable (as in *pet*), but a non-aspirated variant [p] elsewhere (e.g. *loop*). As a phoneme in a particular language has at least one concrete realization, the number of allophones in languages is usually higher than the number of phonemes. We use slashes for transcribing phonemes (phonemic transcription) and square brackets for transcribing allophones (phonetic transcription).

The writing systems that use letters can be organized in different ways – some of them tend to use a letter to denote a phoneme, others are closer to using a letter for an allophone. In Slovenian, the tendency is for one letter to represent one phoneme. For example, the letter "n" stands for the phoneme /n/, which has three allophones: [N] when followed by a velar consonant as in *Anglija* "England" ; [n'] (for some speakers) when followed by [j#] or [jC] as in *konj* "horse", *konjski* "horse-adj" and [n] elsewhere, e.g. *nos* "nose".[2] Despite being phonetically different, all three concrete variants are denoted by the same letter "n".

Nevertheless, in Slovenian, there are fewer letters than phonemes – 25 letters versus 29 phonemes, following Toporišič (2000). As a consequence, the distribution of

[1] The recording for the Slovenian test will be carried out in an anechoic chamber with a noise level below 15 dB(A) using the RØDE NT2000 microphone and RME Babyface Pro external soundcard at a sampling rate of 44.1 kHz.

[2] In this paper we use the machine-readable alphabet MRPA, as in Dobrišek et al. (2002). The symbol "C" is used for "consonant", while the symbol "#" marks the word boundary.

phonemes cannot be established directly from the letter distribution. There are several reasons for there being more phonemes than letters. In some cases, a single letter can stand for more than one phoneme, e.g. the letter "e" can denote /e/ in *led* "ice", /E/ in *žep* "pocket" or /@/ in *pes* "dog". Similarly, the letter "o" can denote /o/ in *nos* "nose" or /O/ in *noga* "leg".[3] The phoneme /dZ/ is not expressed in writing by a single letter, but by using the two-letter combination "dž" (e.g. džip "jeep"). In addition, for the phoneme /@/ no letter is used in some instances, e.g. in many words that contain the consonant /r/ such as *vrt* "garden", *smrt* "death", etc. The same is true of the phoneme /j/, which is not expressed in writing in some combinations (e.g. *pacient* "patient" /pacijent/), but expressed in writing, though not pronounced in other cases, e.g. "nj#" is pronounced either as [n'] or [n] (depending on the speaker), the letter "j" only indicating the fact that the variant of /n/ is palatalized (with the speakers that pronounce the combination as [n']).[4]

3.3. Choosing the reference corpus for Slovenian phoneme distribution

To find a suitable reference corpus for Slovenian phoneme distribution, we refer to CLARIN.SI repository, and examine two corpora of spoken and one corpus of written Slovenian: a) the corpus of spoken Slovenian GOS (its orthographic transcription in standard Slovenian), which contains 1 million words, b) the orthographic transcription of the database SNABI Slovenian Studio Quality Speech Corpus, more precisely its subpart Lingua consisting of 910 sentences taken from different styles of text, such as books and newspapers (Kačič et al. 2002), and c) the corpus of written Slovenian ccKres, which contains 10 million words of different types of texts – from daily newspapers, magazines, books (fiction, non-fiction, textbooks), web pages – and has a balanced genre structure. We then calculate the frequencies of letters in the three corpora and compare them to the seminal work of Jakopin (1999), which analysed a number of literary works in Slovenian. The results are presented in Table 1.

[3] In this work, vowel lenght and stress are not taken into consideration.

[4] Jurgec (2011) proposes that Slovenian has nine vowels and not eight as traditionally assumed. The additional vowel is the low central tense vowel [V] (e.g. in the words *čas* "time", *brat* "brother", etc.). In this paper, we follow the traditional classification as in Toporišič (2000).

	a	b	c	č	d	e	f	g	h	i	j	k	l	m	n	o	p	r	s	š	t	u	v	z	ž
GOS	12.0	1.7	0.6	1.3	3.5	12.5	0.2	1.2	0.9	8.0	4.9	3.9	4.1	4.2	5.9	8.8	3.6	4.5	4.5	1.2	5.2	1.6	3.3	1.9	0.4
ccKres	10.4	1.8	0.9	1.4	3.5	10.2	0.2	1.5	1.1	9.0	4.3	3.7	4.6	3.1	6.9	9.3	3.5	5.3	4.8	1.0	4.6	2.0	4.1	2.2	0.6
Lingua	9.7	1.9	0.7	1.6	3.5	10.9	0.2	1.4	1.2	8.8	4.8	3.6	4.9	3.5	6.3	9.2	3.6	5.1	4.8	1.2	4.5	1.9	4.2	2.2	0.6
Jakopin	10.5	1.9	0.7	1.5	3.4	10.7	0.1	1.6	1.1	9.0	4.7	3.7	5.3	3.3	6.3	9.1	3.4	5.0	5.1	1.0	4.3	1.9	3.8	2.1	0.7

Table 1: Letter frequencies (in %) in three reference corpora and Jakopin (1999)

We find that the letter frequencies in the three corpora agree within approximately 10% (except for the less frequent letters, where the variations are larger), yet GOS has a relatively high proportion of letters “a”, “e” and “m”, possibly because they are used as fillers in spoken Slovenian. Based on the corpus size and the letter distribution we adopt ccKres as the basis for establishing the phonemic balance.

3.4. Establishing Phoneme distribution

To our knowledge, the distribution of Slovenian phonemes has not been thoroughly analysed, which is understandable given the fact that a phoneme is an abstract unit that appears more often in (theoretical) linguistic research, while in the work on corpus linguistics or applied phonetics we usually find analyses based on orthographic or phonetic transcription. To obtain the phonemic distribution, we take the orthographic data, i.e. the letter distribution, as our basis and supplement it with the distribution of particular phonemes in cases where these are not directly evident from the letters (for phonemes /e/, /E/, /@/, /o/, /O/, /dZ/, /j/, see Section 3.2.).[5] This is done by adding the phonemes that are missing in the orthographic transcription (/@/, /j//), subtracting the number of phonemes that are not pronounced (/j/) and by referring to the ratios of the phonemes in the corpus that contains a phonetic transcription (/e/, /E/, /@/, /o/, /O/). For the latter, we refer to the distribution as established in Mihelič (2006), where 300.000 phonetically transcribed sentences are analysed in terms of allophone distribution.[6]

The procedure is described in detail in the following points:

1) All letters in the corpus ccKres are transformed into lower case characters. Next, the standard Slovenian diacritic marks on the letters “a”, “e” and “o” are discarded ("á"→"a", "à"→"a", "é"→"e", "ê"→"e", "è"→"e", "ô"→"o", "ó"→"o"). Finally, all the characters that are not in the standard Slovenian alphabet (except for “đ”) are discarded from the corpus.
2) The number of phonemes /dZ/ is determined by counting the total occurrences of “dž” and “đ”.
3) The number of phonemes /j/ is adjusted by adding the occurrences that are pronounced, but not expressed in writing between the two vowels in the following combinations: "ia", "ie", "io", "ea", "oi". The number of phonemes /j/ is reduced in the instances where the latter is found is spelling, but is not pronounced: nj#, njC, lj#, ljC.
4) The number of phonemes /o/ and /O/ is determined by dividing the number of letters “o” according to the distribution in Mihelič (2006): /o/ (21 % of letter "o" occurrences), /O/ (79 % of letter "o" occurrences).
5) The number of phonemes /e/, /E/ and /@/ is determined by first summing the number of letters “e” plus the number of occurrences of /@/ that are not expressed in writing. According to Toporišič (2000), the phoneme /@/ can be found in combinations with “CrC”, “Cr#”, “#rC”, “vn#”, “jn#”, “ln#”, “lm#”, “jm#”, “lmN”, “jmN”, “jnN”, “lnN”, “vnN”, where “C” stands for any consonant, “N” for any obstruent, and “#” for a word boundary. The total count of these occurrences is divided into the phoneme counts according to the distribution of these three phonemes in Mihelič (2006): /e/ (25 %), /E/ (66 %) and /@/ (9 %).

The proposed phonemic distribution, on which the matrix test for Slovenian is based, is presented in Section 4 in Table 3 and Figure 1 (phonemes and their percentage of occurrence).

4. Results: Matrix Test for Slovenian

The proposal for the Slovenian matrix test, based on the criteria from Section 3, is presented in Table 2.

[5] In principle it would be possible to arrive at the phonemic transcription on the basis on the phonetic transcription. However, in several cases, the allophones of different phonemes overlap and thus make it impossible to obtain a precise phonemic transcription without referring to orthography. For example, the phonemes /l/ and /v/ in the final position are pronounced in the same way. The words *pil* "drink-participle" and *piv* "beer-plural.genitive" share the phonetic transcription /piU/, but are different in terms of phonemic transcription, /pil/ and /piv/, respectively.

[6] Lingua also contains a phonetic transcription that could serve as a basis for establishing the ratios concerning the vowels in question. It is, however, a much smaller corpus in comparison to Mihelič's database (910 versus 300.000 sentences). The ratio concerning "o" is very similar to the one in Mihelič (2006): 75% of letters "o" correspond to the phoneme /O/ and 25% to /o/ (79% vs. 21% in Mihelič (2006)). The ratios for the letter "e" are /E/ (51%), /e/ (45%) and /@/ (4%) and differ considerably to the ones in Mihelič (2006) (66% vs. 25% vs. 9%). We believe that one of the causes for the differences lies in the fact that the pronunciation in Mihelič's corpus relies on the standard, while Lingua contains the transcription of the colloquial speech, mostly the variant from the Štajerska region.

Name	Verb	Numeral	Adjective	Noun
Gregor	kupi (buys)	pet (five)	velikih (big)	stolov (chairs)
Tone	dobi (gets)	šest (six)	lepih (beautiful)	copat (slippers)
Jure	najde (finds)	sedem (seven)	novih (new)	škatel (boxes)
Urban	skrije (hides)	osem (eight)	čudnih (strange)	avtov (cars)
Sašo	vzame (takes)	enajst (eleven)	starih (old)	zvezkov (notebooks)
Branka	ima (has)	sto (hundred)	dobrih (good)	koles (bicycles)
Jana	pelje (conveys)	tristo (three hundred)	dragih (expensive)	kamnov (stones)
Nada	nese (carries)	tisoč (thousand)	modrih (blue)	majic (T-shirts)
Lara	proda (sells)	nekaj (some)	rumenih (yellow)	loncev (pots)
Petra	išče (looks for)	malo (few)	zelenih (green)	nožev (knives)

Table 2: The proposed fifty-word matrix for the Slovenian Matrix Test.

The phonemic distribution in ccKres (as established in the previous section) in comparison to the phonemic distribution in the Slovenian fifty-word matrix is presented in Table 3 and Figure 1.

phoneme	test	ccKres
a	9,88	10.46
i	7,51	9.04
O	7,11	7.37
E	6,72	7.08
n	6,32	6.95
r	5,93	5.36
s	5,14	4.79
t	5,53	4.64
l	3,95	4.63
v	4,35	4.17

phoneme	test	ccKres
k	3,56	3.68
d	3,56	3.51
p	2,77	3.48
j	3,16	3.28
m	3,56	3.12
e	3,56	2.68
z	1,58	2.20
u	1,98	2.04
o	1,58	1.96
b	1,58	1.84

phoneme	test	ccKres
g	1,19	1.50
tS	1,19	1.40
x	3,95	1.11
S	1,58	0.97
@	1,19	0.97
c	1,19	0.90
Z	0,40	0.61
f	0,00	0.24
dZ	0,00	0.01

Table 3: Phoneme frequencies (in %) in the proposed Slovenian Matrix Test and in the corpus ccKres.

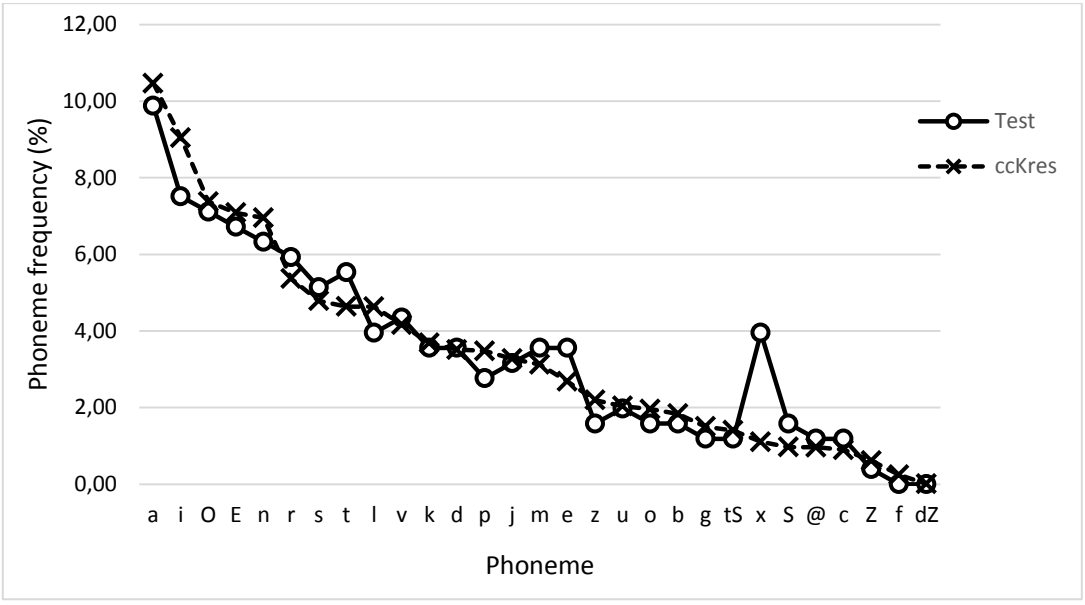

Figure 1: Phoneme frequencies (in %) in the proposed Slovenian Matrix Test and in the corpus ccKres.

The phonemic balance achieved in the Slovenian matrix test is comparable to the one in Polish and Russian, see Ozimek et al. (2010) and Warzybok et al. (2015) for a comparison. It can be seen from the figures that the phoneme /x/ is overrepresented, as the number of occurrences in the test is approximately 3.5 times higher than the number of occurrences in the language (similarly in the Polish and Russian tests). This can be explained by the inherent nature of the sentence structure: Adjectives that follow quantifier expressions and the numerals from five on must appear in their genitive plural form, which ends in the phoneme /x/ with all adjectives. The phoneme /e/ is slightly over-represented because it appears in several numerals.

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