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1 An Italian matrix sentence test for the evaluation of speech intelligibility in noise

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3 Giuseppina Emma Puglisi^{a,*}

4 Anna Warzybok^b

5 Sabine Hochmuth^b

6 Chiara Visentin^c

7 Arianna Astolfi^a

8 Nicola Prodi^c

9 Birger Kollmeier^b

10

11 ^aPolitecnico di Torino

12 Department of Energy

13 Corso Duca degli Abruzzi, 24, 10129, Torino, Italy

14

15 ^bUniversity of Oldenburg

16 Medizinische Physik and Cluster of Excellence Hearing4all

17 D-26111, Oldenburg, Germany

18

19 ^cUniversità di Ferrara

20 Department of Engineering

21 Via Saragat 1, 44122, Ferrara, Italy

22

23 Key words: speech perception, speech audiometry, speech reception threshold, Italian
24 speech recognition test

25

26 Abbreviations:

27 ANOVA Analysis of Variance

1

2 SRT Speech Reception Threshold

3

4 SNR Signal-to-Noise Ratio

5

6 S50 slope of intelligibility function

7

8 *) Author to whom correspondence should be addressed.

9

10 Electronic mail: giuseppina.puglisi@polito.it

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12

1 ABSTRACT

2 Objective: Development of an Italian matrix sentence test for the assessment of speech
3 intelligibility in noise. Design: The development of the test included the selection, recording,
4 optimization with level adjustment, and evaluation of speech material. The training effect
5 was assessed adaptively during the evaluation measurements with 6 lists of 20 sentences,
6 using open- and closed-set response formats. Reference data were established for normal-
7 hearing listeners with adaptive measurements. Equivalence of the test lists was investigated
8 using the open-set response format at three signal-to-noise ratios (SNRs). Study sample: 55
9 normal-hearing Italian mother-tongue listeners. Results: The evaluation measurements at
10 fixed SNRs resulted in a mean speech reception threshold (SRT) of -7.3 ± 0.2 dB SNR and
11 slope of 13.3 ± 1.2 %/dB. The major training effect of 1.5 dB was observed for the first two
12 consecutive measurements. Mean SRTs of -6.7 ± 0.7 dB SNR and -7.4 ± 0.7 dB SNR were
13 found from the third till the sixth adaptive measurement for open- and closed-set test
14 response formats, respectively. Conclusions: A good agreement has been found between the
15 SRTs and slope and those of other matrix tests. Since sentences are difficult to memorize, the
16 Italian matrix test is suitable for repeated measurements.

17

18

1 INTRODUCTION

2 Even though the Italian language is the 2nd most commonly spoken language in Europe
3 (European Commission, 2012) and the 21st most commonly spoken language in the world
4 (Lewis et al., 2014) only a few speech recognition tests have been developed so far to
5 evaluate speech intelligibility for both audiology and research purposes (e.g. for intelligibility
6 measurements in classrooms or in workspaces). Moreover, most of them have not been
7 optimized for speech intelligibility in noise. This paper therefore describes the construction
8 and evaluation of an Italian sentence test with the matrix test format in order to be
9 compatible with an increasing number of tests that implement this format in other languages
10 (Kollmeier et al., 2015).

11 The most frequently used speech intelligibility test for the Italian language is based on
12 meaningful mono- or disyllabic words (Bocca & Pellegrini, 1950) distributed over 6 lists
13 composed of 50 words each. Since meaningful monosyllabic words are rarer in Italian than
14 disyllabic words, a disyllabic test was proposed by Turrini et al. (1993) which was optimized
15 with regard to **phonemic balancing** and word familiarity.

16 The other speech audiometry tests that are available in Italian are based on lists of
17 nonsense logatoms with a CVCV structure (Azzi, 1950), meaningful sentences (Cutugno et
18 al., 2000) and syntactically fixed but meaningless sentences (Antonelli et al., 1977).

19 The main problem with most of the aforementioned tests is their limited accuracy
20 which is due both to the comparatively small number of test items per test list (that is 5, 10
21 or 20 items, Prosser & Martini, 2007) and to the variability in intelligibility across test items,
22 which were not controlled during the design and construction of the tests (Antonelli et al.,
23 1977). In addition, the limited accuracy in existing tests is related to the lack **of** the
24 optimization of speech items in terms of intelligibility. In Cutugno et al. (2000) competition

1 noises (babble, traffic, pink and continuous speech) are recorded and provided together with
2 sentences on two tracks of a CD. Optimization only consists in the equalization of the root
3 mean square (RMS) of all speech items and noise signals. Furthermore, no information is
4 available about perceptual equivalence of the test lists or reliability of the test. The effect
5 due to the availability of only a small number of test items can partially be compensated for
6 by combining test lists, e.g. performing adaptive test procedures and stopping the
7 measurement after, e.g., 8-10 reversals of the adaptive track, or by using test items with
8 several independent elements, such as, e.g., short sentences. Even then, the difference in
9 redundancy (which is higher for meaningful sentences, lower for semantically correct, but
10 meaningless sentences, and even lower for logatomes) again reduces the number of
11 independent elements and hence the maximum achievable accuracy per time unit. The
12 resulting variance in speech intelligibility makes the comparison of results between different
13 listeners or within the same listener under different conditions difficult (e.g. before and after
14 the application of a hearing aid; Prosser & Martini, 2007).

15 This work describes the development of a matrix sentence test in the Italian language
16 which was set up in order to have an efficient and valid tool for the testing of speech
17 intelligibility in noise. The developmental steps are compatible to those established for other
18 matrix tests (Kollmeier et al., 2015), and a comparison between languages is therefore
19 possible. Due to using semantically unpredictable sentences with a fixed syntactic structure
20 (name-verb-number-noun-adjective; e.g. *Sofia trascina poche matite utili*, which is Italian for
21 “Sophie drags a few useful pencils”), the test lists can be used for repeated measurements
22 with the same listener and a high accuracy can thus be achieved with an appropriately high
23 number of concatenated test lists. A further advantage of the matrix test is its possibility of
24 using a closed-set response format: The listener may respond not by repeating the sentence

1 he/she heard but only has to press appropriate buttons in the response matrix. This makes
2 the test suitable for testing a listener in her or his native language, even if the test
3 administrator does not understand the language.

4 The test development procedure consisted selecting 50 words for a base matrix,
5 recording the words while taking into account co-articulation effects, generating masking
6 noise, optimizing the speech material by applying level adjustments, and then taking
7 evaluation measurements. Finally, the Italian matrix test was compared with existing matrix
8 tests to respond to the three main research aims. First, to understand if the Italian matrix
9 test shares properties with matrix tests in other Romance languages. Second, to evaluate
10 whether it is possible to observe the same training effect for open- and closed-set response
11 formats, as in other languages. Third, to investigate the test-retest reliability of the speech
12 reception thresholds (SRT), in comparison to other Matrix tests.

13

14 SPEECH MATERIAL

15 In order to establish the 50-word base matrix, which consists of 10 names, 10 verbs, 10
16 numerals, 10 adjectives, and 10 nouns, two- and three-syllabic words were selected from
17 among the most frequently used words in the spoken Italian language (see Table 1). Since
18 commonly used words were chosen (based on frequency dictionary of Bortolini et al., 1972),
19 the listeners were familiar with the words of base matrix. This minimized the influence of the
20 listener's linguistic competence on speech intelligibility. The phoneme distribution of the 50
21 words in the base matrix was compared with a reference phoneme distribution of the Italian
22 language taken from Tonelli et al. (1998). In the current study, singleton and geminate
23 consonants were summarized as one phoneme class. The phoneme distribution of the base
24 matrix was close to the reference distribution, with a maximum deviation of 2.2% for a
25 phoneme /o/ (see Figure 1).

1 [FIGURE 1 about here]

2 By selecting the words from the sequence provided in the base matrix, grammatically
3 correct but semantically unpredictable sentences were generated as a random combination
4 of words from each word group (e.g. *Andrea manda molte tazze normali*, which is Italian for
5 “Andrea sends many normal mugs”).

6 [TABLE 1 about here]

7

8 RECORDINGS, CUTTINGS AND RESYNTHESIS OF SENTENCES

9 The sentences were recorded according to the procedure proposed by Wagener et al. (1999
10 c). One hundred sentences were generated and recorded, so that all the possible
11 combinations of two consecutive words were included to capture the co-articulation
12 between two successive words. The sentences were produced by a native Italian female
13 speaker with standard Italian pronunciation. She was asked to pronounce words with a
14 natural intonation and accentuation, and at a moderate constant speaking rate. The
15 recordings were done in a sound-attenuated booth (fulfilling the requirements of ISO 8253-3,
16 2012) using a Neumann 184 microphone with a cardioid characteristic and a Fireface UC
17 soundcard with a sampling rate of 44.1 kHz and a resolution of 32 bits. The signals were
18 saved on a PC hard-disc using Adobe Audition 2.0.

19 The recorded sentences were filtered with a 40Hz-high-pass filter and each sentence
20 was set to the same root-mean-square level. Then, the sentences were cut into single words
21 at a zero-crossing of the waveform, which resulted in 10 different realizations of each word
22 of the base matrix. The initial cuttings were performed very close to the beginning of each
23 word, while the final cut close was made to the beginning of the consecutive word in order
24 to include the co-articulation of the consecutive word at the ending of the words. This means

1 that each realization included a different co-articulation at the end. Thirty test lists of ten
 2 sentences were resynthesized for each list that contained all of the fifty words of the base
 3 matrix. Each word realization was included 3 times in these 300 sentences. In order to
 4 minimize the artefacts due to the resynthesis, individual overlapping times of between 0 and
 5 20 ms were applied at the transitions between words.

6 The masking noise was generated through a 30-fold overlapping of all the sentences,
 7 applying different silent intervals between sentences (for details see Wagener et al., 2003).
 8 This resulted in a stationary noise with a long-term spectrum that matched the long-term
 9 spectrum of the speech material.

10

11 OPTIMIZATION MEASUREMENTS

12 Accurate speech intelligibility measurements require a speech recognition test with a steep
 13 test-specific intelligibility function (e.g. Plomp & Mimpen, 1979; Kollmeier, 1990; Wagener et
 14 al, 1999b). The slope of a test-specific intelligibility function ($S50_{test}$, Equation 1) can be
 15 considered as the convolution of the mean slope of the word-specific intelligibility functions
 16 ($S50_{mean}$) and the distribution of the word-specific SRTs (σ_{SRT}), as shown by Kollmeier (1990,
 17 2015).

$$18 \quad S50_{test} \approx \frac{S50_{mean}}{\sqrt{1 + \frac{16S50_{mean}^2 \sigma_{SRT}^2}{(\ln(2e^{1/2} - 1 + 2e^{1/4}))^2}}} \quad (1)$$

19 where: $S50_{mean}$ is the mean slope of the word-specific intelligibility functions and σ_{SRT} is the
 20 standard deviation across all the word-specific SRTs.

1 The steepness of the test-specific function can be increased by decreasing the spread in the
2 word-specific SRTs. The spread of the word-specific SRTs can be decreased by applying level
3 adjustments, i.e. less intelligible words than the average ($SRT_{\text{word}} > SRT_{\text{mean}}$) are increased in
4 level whereas words of better intelligibility ($SRT_{\text{word}} < SRT_{\text{mean}}$) are decreased in level. The
5 optimization measurements were aimed at obtaining word-specific intelligibility functions
6 with their parameters (i.e. word-specific SRT and S50).

7

8 *Listeners*

9 Nineteen native Italian listeners participated in the optimization measurement procedure,
10 which took place in Oldenburg, Germany. Their ages ranged from between 19 and 31, with a
11 mean age of 23.9. The pure-tone threshold did not exceed 15 dB HL at octave frequencies of
12 between 125 and 8000 Hz. The listeners had been in Germany for one year at most at the
13 time of the measurements. They were all born and raised in Italy. The listeners were paid for
14 participating in the measurements.

15

16 *Procedure and equipment*

17 The Oldenburg Measurement Applications software (HörTech GmbH, Oldenburg,
18 www.hoertech.de) was used for the speech intelligibility measurements. Speech and noise
19 signals were presented monaurally to the listeners' preferred ear by means of free-field
20 equalized headphones (Sennheiser model HDA200). The measurement setup was calibrated
21 to dB SPL using Brüel & Kjær instruments, i.e. artificial ear type 4153, microphone type 4134,
22 preamplifier type 2669 and amplifier type 2610.

23 Thirty base lists of ten sentences each were constructed, considering that each list
24 contained all the words of the basic matrix in different combinations and thus was

1 phonetically balanced with respect to the phoneme distribution of the Italian language
2 reported in Tonelli et al. (1998). Prior to the first measurement session, the listeners were
3 familiarized with the speech material through a presentation of two test lists. The first
4 training list was presented without any interferer at 65 dB SPL. The second training list was
5 presented at a fixed SNR of 0 dB, which resulted in an intelligibility of almost 100%. After the
6 training session, speech intelligibility was measured at fixed SNRs in the -18 dB to 4 dB range
7 in 2 dB steps. The sound pressure level of the background noise was kept constant at 65 dB
8 SPL, and was started and ended 500 ms before and after presentation of the sentence
9 presentation. Fifty ms rising and falling ramps were applied to the noise signal (using a Hann
10 window) to prevent abrupt signal onset and offset. The order of the sentences in a list, the
11 SNR, and the list index were randomized across listeners. The measurements were
12 conducted with the open-set response format, in which the listener's task was to repeat the
13 words he/she understood and the test administrator marked the correct responses on a
14 display. The responses were stored using word-scoring, indicating that each word in a
15 sentence was scored separately.

16 In order to obtain the word-specific speech intelligibility functions, a logistic model
17 function (Equation 2) was fitted to the measured data (SI) using a maximum likelihood
18 procedure:

$$19 \quad SI_{word}(SNR) = \frac{100}{1 + e^{4.550(SRT - SNR)}} \quad (2)$$

20 where SI_{word} is the intelligibility function of the word.

21

22 *Results*

1 The optimization measurements resulted in a mean word-specific SRT of -8.3 ± 3.7 dB SNR
2 and a median slope of 17.7 %/dB over all of the 500 word realizations. The test-specific slope
3 was predicted by means of Equation 1 and resulted in 9.2 %/dB. Eleven realizations of words
4 were excluded from the final test material. With each excluded realization a whole base list
5 also had to be excluded, which resulted in 12 base lists remaining at the end of the
6 optimization procedure. Realizations were excluded for which no adequate fitting was
7 possible or whose SRTs differed considerably from the general SRT of the respective word.
8 Included word realizations did not deviate more than 8.5 dB from the average word-specific
9 SRT.

10 In order to homogenize the intelligibility of the speech material, level adjustments
11 were applied to each remaining word realization (384 out of 500). The level adjustments
12 were limited to ± 3 dB to preserve a natural intonation of the optimized sentences, which
13 was judged by two native Italian listeners. The level adjustments and list exclusions resulted
14 in a mean SRT of -8.3 ± 1.4 dB SNR and a median slope of 18.0 %/dB over the remaining 384
15 word realizations included in the 12 remaining lists. In other words, the standard deviation of
16 the word-specific SRT was decreased by 2.3 dB, which resulted in the test-specific slope
17 becoming steeper, that is, from 9.2 %/dB to 15.2 %/dB, according to Equation 1.
18 Table 2 summarizes the measured and predicted values that were obtained from the
19 optimization procedure.

20 [TABLE 2 about here]

21

22 EVALUATION MEASUREMENTS

23 The evaluation measurements had various objectives. Besides verifying the characteristics of
24 the optimized speech material, proving the equivalence of the base lists remaining after the

1 optimization procedure, and establishing reference data for normal-hearing listeners, the
2 training effect was addressed, as investigated for other matrix tests.

3

4 *Listeners*

5 Fifteen native Italian listeners were tested in Torino (9 female and 6 male subjects, mean age
6 28) and 11 listeners in Ferrara (5 female and 6 male subjects, mean age 23) using the open-
7 set response format. The hearing status of the listeners who participated in the
8 measurements in Ferrara was assessed via self-reporting. Normal hearing of the listeners
9 measured in Torino was **proven** by means of pure tone audiometry. The pure tone thresholds
10 did not exceed 20 dB HL at octave frequencies from 125 to 8000 Hz. The training effect, using
11 the closed-set response format, was evaluated with a separate group of 10 listeners in
12 Ferrara (5 female and 5 male subjects, mean age 24 years).

13

14 *Procedure*

15 The measurement setup in Torino and Ferrara consisted of a notebook with an earbox 'ear
16 3.0' sound card (Auritec, Hamburg, Germany) and free-field equalized Sennheiser HDA200
17 headphones. The measurement setup used in Torino was calibrated in the same way and
18 with the same equipment as described in the optimization measurements part. In Torino, a
19 type 2260 amplifier was used instead of a type 2610 amplifier. The measurements in Torino
20 took place in a **sound-treated booth** that complied with **ANSI S3.1-1999 (R2008)**, while a
21 room with low background noise ($L_{eq} = 43.3$ dB) in the University building was selected in
22 Ferrara. **All the evaluation measurements were conducted monaurally. Each listener could**
23 **indicate at which of both ears all measurements should be performed.**

1 The training effect was evaluated both in a closed- and open-set response format. In
2 the closed-set response format, after the listener listens to the sentence, he/she was given a
3 digital interface that showed a panel containing the 50 words of the base matrix: in this way,
4 the listener can indicate the words they have understood on the panel. Instead, in the
5 open-set response format the subject has to repeat the words he/she has understood and
6 the experimenter has to indicate the correctly repeated words on a display. The SRTs were
7 measured, in order to evaluate the training effect, using an adaptive procedure described by
8 Brand and Kollmeier (2002) with six double lists of 20 sentences (consisting of all the 12 base
9 lists available after optimization). The initial SNR in the adaptive procedure was set at 0 dB,
10 the noise level was fixed at 65 dB SPL and the speech signal was varied to converge to 50% of
11 intelligibility. The answers were stored using word-scoring, i.e. each word in a sentence was
12 scored separately. The SRT was estimated using a maximum likelihood procedure. The order
13 of the test lists was randomized across listeners.

14 In order to evaluate list equivalence, six double lists (the same as those used in the
15 training session) were presented to each listener at fixed SNRs of -4.5 dB SNR, -7 dB SNR and
16 -9.5 dB SNR corresponding to recognition rates of about 80 %, 50 % and 20 %, respectively.
17 The noise level was kept constant at a level of 65 dB SPL. This part of evaluation
18 measurements was performed in Torino with 11 out of 15 listeners participating previously in
19 the training effect measurements. List-specific intelligibility functions for each of 12 base lists
20 were obtained by fitting the logistic model function (Equation 2) to the mean intelligibility
21 scores averaged across all listeners.

22

23 RESULTS

24 *Training effect*

1 The mean SRTs and corresponding standard deviations are shown in Figure 2 as a function of
2 the sequence of measurements. The SRTs measured with both the open- and closed-
3 response formats are shown.

4 [FIGURE 2 about here]

5 A mixed design repeated-measures analysis of variance (ANOVA) was conducted for
6 the open-set response format with the measurement site as the between group factor (two
7 levels) and the sequence of measurements as the within group factor (six levels). No
8 statistical difference was found between the two measurement sites ($F(1, 24) = 0.41, p =$
9 0.526), but a statistically significant main effect of the temporal measurement order ($F(5,$
10 $120) = 80.29, p < 0.001$) was found as well as a significant interaction between the
11 measurement order and the test site ($F(5, 120) = 3.05, p = 0.019$). A separate mixed design
12 repeated-measures ANOVA was conducted, with the response format as the between group
13 factor (two levels) and the sequence of measurements as the within group factor (six levels).
14 Mauchly's test was carried out and it indicated that the assumption of sphericity had been
15 violated for the main effect of the test type, $\chi^2(2) = 27.20, p = 0.018$, and the degrees of
16 freedom were therefore corrected using Greenhouse-Geisser estimates of sphericity
17 ($\epsilon = 0.756$). A statistical difference was found between the open- and closed-set response
18 formats ($F(1, 34) = 14.33; p = 0.001$) and for the main effect of the measurement order
19 ($F(3.78, 128.46) = 73.17; p < 0.001$). ANOVA revealed no significant interaction between the
20 response format and measurement order ($F(3.78, 128.46) = 0.48; p = 0.738$). The largest
21 improvement in SRT, that is, of 1.2 dB for the open-set response format and 1.1 dB for the
22 closed-set response format, was observed between the first and the second measurements.
23 It decreased to 0.5 dB for the open-set response format and 0.3 dB for the closed-set
24 response format between the second and third measurement. From the third measurement

1 onwards, only small improvements were found. Therefore, as for other languages, the
2 reference data was obtained by separately averaging the SRTs of the third measurement to
3 the last one, , for the open- and closed-set response formats. This resulted in a mean SRT of -
4 6.8 ± 0.8 dB SNR for the open-set response format and of -7.3 ± 0.8 dB SNR for the closed-set
5 response format.

6 The test-retest reliability was calculated in the same way as for the French matrix test
7 (Jansen et al., 2012), that is, on the basis of repeatable measured SRT with an adaptive
8 procedure. Only SRTs from the third to sixth measurements were considered to account for
9 the training effect. Within-subject variabilities of 0.5 dB and 0.6 dB were found for the open-
10 and the closed-set response formats, respectively.

11 *Base list equivalence*

12 The mean intelligibility scores measured with the open-set format at 3 SNRs and the fitted
13 list-specific intelligibility functions of the 12 base lists of 10 sentences each are summarized
14 in Table 3. The mean list-specific SRT and slope were -7.3 ± 0.2 dB SNR and 13.3 ± 1.2 %/dB,
15 respectively. The lowest and the highest SRTs across lists were -7.6 dB SNR and -7.2 dB SNR,
16 respectively, while the lowest and highest slopes across the lists were 11.1 %/dB and 15.6
17 %/dB, respectively. Although the slope on the intelligibility function for the closed-set format
18 was not measured in this study, according to Hochmuth et al. (2012) it is expected that no
19 significant difference is found between the two formats.

20 [TABLE 3 about here]

21 In order to examine the equivalence of the test lists and determine the standard deviation
22 across listeners, the logistic function was also fitted separately for each listener and each
23 list. Repeated measures ANOVA with SRT and S50 as the main factors revealed no statistical

1 differences in terms of SRT $F(11, 110) = 1.6, p = 0.11$ and S50 $F(11, 110) = 1.64, p = 0.098$. The
2 mean SRT and S50 averaged across the listeners and lists were -7.4 ± 0.9 dB SNR and
3 14.3 ± 3.6 %/dB, respectively.

4

5 DISCUSSION

6 *Evaluation*

7

8 The optimization of the speech material applied to the word realizations decreased the
9 variability of the word-specific SRTs by 2.3 dB (from 3.7 dB to 1.4 dB) and thus, according to
10 Kollmeier's probabilistic model (1990, 2015), increased the predicted test-specific slope by
11 6 %/dB (from 9.2 %/dB to 15.2 %/dB). The predicted increase in the test-specific slope for the
12 optimized speech material was confirmed in the evaluation measurements. The measured
13 mean list-specific slope was 13.3 %/dB, which is 4.1 %/dB higher than the one obtained for
14 the speech material prior to optimization. This high slope of the Italian matrix test qualifies it
15 for accurate and efficient speech intelligibility measurements.

16 The mean list-specific slope is highly comparable to those obtained for matrix tests in other
17 Romance languages, i.e. for Spanish (13.2 %/dB; Hochmuth et al., 2012) and for French
18 (14.0 %/dB; Jansen et al., 2012), and is close to those of other languages, such as Russian
19 (13.8 %/dB, Warzybok et al., 2015) or Danish (12.6 %/dB; Wagener et al., 2003). Higher test-
20 specific intelligibility function slopes were found for the German and Polish matrix tests
21 (slope of 17.1 %/dB in both cases, Wagener et al., 1999a; Ozimek et al., 2010). The
22 differences in slope across languages may be related to the specific speaker's characteristics
23 or to the capability of discrimination of phonemes in noise which may be different from
24 language to language. Even though the slopes for the Italian, Spanish and French matrix tests

1 are remarkably similar, they are too close to the values of the other languages to be
2 distinguishable as a separate entity.

3 A comparison with the existing Italian speech recognition tests is difficult or even
4 impossible for several reasons. For example, the development of the speech material with
5 meaningless sentences (Antonelli, 1977) was based on statistical criteria that only accounted
6 for usage, frequency, and dispersion of the words; however, the speech material was not
7 optimized in terms of intelligibility. In addition, Prosser & Martini (2007) argued that the
8 existing Italian audiometry tests reveal a high variability in intelligibility scores since only a
9 small number of items are used clinically. Finally, some of the papers about the development
10 of Italian speech recognition tests are only available in a very limited printed version, and are
11 therefore difficult to have access to.

12

13 *Training effect and base list equivalence*

14 As far as the temporal measurement effect is concerned, denoted in the following as
15 “training effect”, the present work focused on both open- and closed-set response formats
16 which resulted in findings comparable to previous matrix tests (Hochmuth et al., 2012;
17 Warzybok et al., 2015). As for other languages, independent of the response format, the
18 major improvement in SRT was observed between the first two measurements and it then
19 decreased to a value below 1 dB after the second measured list (see Kollmeier et al., 2015).
20 Since no interaction between the temporal order and response format was found, it can be
21 concluded that the amount of training required to obtain stable results is the same for both
22 response formats. This is again in agreement with the matrix tests for other languages
23 (Kollmeier et al., 2015). Furthermore, it can be postulated that the training effect is language
24 independent and related to the test structure. Following the recommendation for other

1 languages, two test lists of 20 sentences each are recommended to account for training in
2 order to obtain stable and repeatable results.

3 For the open-set response format, a significant interaction of temporal measurement
4 and test site was found. It is related to fact that up to the fifth measurement the SRTs
5 measured in Torino and Ferrara were very close to each other, whereas they slightly differed
6 in the sixth measurement. For the last training list, listeners measured in Ferrara showed on
7 average 0.8 dB lower SRT than listeners from Torino. However, this difference is in the range
8 of the test accuracy (defined by the standard deviation of the reference SRT., It can therefore
9 be assumed as being irrelevant from an audiological point of view. The mean SRT for the
10 open-set response format was 0.7 dB higher than the mean SRT for the closed-set response
11 format. This difference between the two response formats was again in line with previous
12 findings by Hochmuth et al. (2012) for the Spanish matrix test or by Warzybok et al. (2015)
13 for the Russian matrix test, which showed differences of 1 dB and 0.6 dB, respectively. These
14 findings indicate that the visual presentation of word alternatives which is available in the
15 closed-set response format may help a listener to better recognize the words of a sentence
16 that were previously presented acoustically, thus lower SRTs can be achieved. **In clinical**
17 **settings**, the close-set version is mainly recommended for patients of a different native
18 language than the test instructor. The measurement in open-set format takes usually less
19 time **than** in the closed-set format. Therefore for a clinical **practice**, when the native language
20 of a patient and a test instructor is the same, the open-set format is recommended. The
21 reference data obtained from the adaptive measurements (-6.8 ± 0.8 dB SNR and -7.3 ± 0.8
22 dB SNR for the open and close-set response formats, respectively) are close to those of the
23 Spanish test in both the open- and closed-set response formats (-6.2 ± 0.8 and -7.2 ± 0.7 ,
24 respectively).

1 The high test-retest reliability of the Italian matrix test (0.5 dB for the open- and
2 0.6 dB for the closed-set response format) is very close to the reliability of the French matrix
3 test (0.4 dB for the closed-set response format; Jansen et al., 2012) and of the Russian matrix
4 (0.6 dB for the open- and 0.5 dB for the closed-set response formats; Warzybok et al., 2015).

5 The evaluation measurements have also confirmed the equivalence of the test lists.
6 Neither SRT nor S50 differed significantly across test lists. Furthermore, the small difference
7 in SRTs between the test lists of 0.2 dB is on average comparable with the findings of matrix
8 tests in the other languages which showed a standard deviation across test lists of between
9 0.1 dB and 0.2 dB (see Kollmeier et al., 2015 for an overview). Furthermore, the differences
10 across test lists for SRT and S50 are smaller than the differences across normal-hearing
11 listeners, which again indicates a high homogeneity of the speech material between the test
12 lists. This is an effective improvement to the available tests for speech audiometry in Italian,
13 in which the results are less accurate because of the high variability of the number of items
14 per list (Prosser & Martini, 2007).

15

16 CONCLUSIONS

17 The matrix sentence test has been developed for the Italian language to allow measurements
18 to be made in an open-set response format with an experimenter present, as well as in a
19 self-administered closed-set response format. The values obtained from the evaluation
20 measurements, i.e., reference data for adaptive measurements, parameters of the
21 psychometric function, the test-list equivalence, training effect and test-retest reliability,
22 have been shown to be similar to the values obtained in matrix tests in other languages.

23 The adaptive measurements that were introduced resulted in a reference SRT of -
24 6.8 ± 0.8 dB SNR for the open-set and -7.3 ± 0.8 dB SNR for the closed-set response formats,

1 respectively. The measurements at fixed SNRs for the determination of the psychometric
2 function of the Italian matrix test resulted in an SRT of -7.3 dB SNR and a slope of 13.3 %/dB.
3 It was possible to obtain a high test list equivalence with a standard deviation in SRT across
4 test lists of 0.2 dB.

5 Moreover, the test has yielded a high test-retest reliability of 0.5 dB for the open-set
6 and 0.6 dB for the closed-set response formats.

7

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12 listeners in Torino and for the opportunity of conducting measurements in a clinical
13 environment. We would also like to thank Rossana Carta for the data collecting in
14 Oldenburg.

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1 List of tables

2 Table 1: Basic word matrix of the Italian matrix sentence test. Words in bold indicate an
3 example of one randomly built up sentence.

| <i>Names</i> | <i>Verbs</i> | <i>Numerals</i> | <i>Nouns</i> | <i>Adjectives</i> | <i>English translation</i> |
|--------------|----------------|-----------------|----------------|-------------------|---|
| Sofia | compra | due | scatole | azzurre | <i>Sofia buys two light-blue boxes.</i> |
| Marco | vuole | poche | matite | piccole | <i>Marco wants a few small pencils.</i> |
| Anna | prende | quattro | tazze | normali | <i>Anna takes four normal cups.</i> |
| Sara | dipinge | cinque | pietre | nuove | <i>Sara paints five new stones.</i> |
| Chiara | vede | molte | tavole | belle | <i>Chiara sees many nice desks.</i> |
| Maria | cerca | sette | palle | bianche | <i>Maria looks for seven white balls.</i> |
| Luca | trascina | otto | macchine | grandi | <i>Luca drags eight big cars.</i> |
| Andrea | regala | nove | sedie | utili | <i>Andrea donates nine useful chairs.</i> |
| Matteo | possiede | dieci | bottiglie | nera | <i>Matteo owns ten black bottles.</i> |
| Simone | manda | venti | porte | rosse | <i>Simone sends twenty red doors.</i> |

4

5 Table 2: Mean results from the optimization procedure regarding word-specific SRTs and
6 their standard deviation ($SD_{SRT\text{words}}$), as well as word-specific slopes ($S50_{\text{words}}$) and predicted
7 test-specific slopes ($S50_{\text{test}}$) according to Equation 1 before and after level adjustment and
8 test list selection. The mean list-specific SRT and slope ($S50_{\text{test}}$) measured in the evaluation
9 procedure are also given.

| | Optimization | | | Evaluation |
|---|---|---|---|-----------------------|
| | Before level adjustments (500 word realizations) | Before level adjustments (384 word realizations) | After level adjustment (384 word realizations) | List-specific results |
| SRT /dB SNR | -8.3 | -8.3 | -8.3 | -7.3 |
| $SD_{SRT\text{words}}$ / dB SNR | 3.7 | 3.4 | 1.4 | - |
| $S50_{\text{words}}$ / %/dB | 17.7 | 18.0 | 18.0 | - |
| $S50_{\text{test}}$ / %/dB | 9.2 | 9.7 | 15.2 | 13.3 |

10

11 Table 3: Mean list-specific intelligibility scores measured at SNRs of -9.5, -7, and -4.5 dB SNR
12 and list-specific SRT and S50 with mean SRT and S50 averaged across 12 base lists.

13

| List | Scores [%] | | | SRT [dB SNR] | S50 [%/dB] |
|-----------|----------------|----------------|----------------|-----------------|---------------|
| | -9.5 dB SNR | -7.0 dB SNR | -4.5 dB SNR | | |
| 1 | 23.1 | 62.5 | 80.9 | -7.5 | 13.4 |
| 2 | 22.9 | 52.9 | 78.7 | -7.2 | 12.6 |
| 3 | 21.1 | 58.9 | 85.6 | -7.5 | 15.6 |
| 4 | 26.5 | 56.5 | 85.8 | -7.6 | 14.0 |
| 5 | 20.5 | 52.9 | 82.4 | -7.2 | 14.5 |
| 6 | 22.7 | 54.9 | 78.5 | -7.2 | 12.6 |
| 7 | 21.1 | 53.8 | 79.8 | -7.2 | 13.5 |
| 8 | 25.8 | 55.5 | 82.7 | -7.5 | 13.1 |
| 9 | 27.1 | 52.5 | 77.5 | -7.3 | 11.1 |
| 10 | 23.6 | 54.0 | 83.5 | -7.4 | 13.9 |
| 11 | 26.4 | 52.7 | 79.3 | -7.3 | 11.8 |
| 12 | 26.2 | 54.9 | 84.0 | -7.5 | 13.4 |
| | | | MEAN | -7.3 | 13.3 |
| | | | SD | 0.2 | 1.2 |

1

2

3

4

1 List of figures

2 Figure 1: Phoneme distribution of the Italian matrix test (gray squares) and the reference
3 phoneme distribution for the Italian language (black triangles). The phonemes have been
4 transcribed using the International Phonetic Alphabet symbols.

5

6 Figure 2: Mean SRTs and corresponding standard deviations of the six subsequent training
7 measurements for the open-set response format (measurements from Torino, T, with
8 squares, measurements from Ferrara, F, with circles) and for the closed-set response format
9 (triangles) as a function of the measurements sequence.