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VTMR, a New Speech Audiometry Test With Verbal Tasks and Motor Responses

Federica Di Berardino, MD, PhD; Stella Forti, BMath; Antonio Cesarani, MD, PhD

Objectives: The aim of this study was to design a complementary speech audiometry test using verbal tasks and motor responses (VTMR) to assess the ability of a subject to understand and perform simple motor tasks with 3-dimensional objects, to describe its construction, and to show the preliminary results of a pilot study on the Italian version of the test.

Methods: The items used in the test setting included 1 base, 1 hammer, 1 wooden structure with 4 sticks, and 5 rings of different colors and 20 lists with 5 verbal tasks per list. The VTMR test and bisyllabic speech audiometry were evaluated in normal-hearing subjects with and without cognitive impairment and in subjects with sensorineural hearing loss.

Results: All normal-hearing subjects without cognitive impairment performed the VTMR tasks (100%) correctly at 35 dB sound pressure level. In subjects with sensorineural hearing loss, the percentage of correct answers was significantly higher for the VTMR test than for bisyllabic speech audiometry above 50 dB sound pressure level. This percentage was higher for the VTMR also in normal-hearing subjects with poor cognitive skills.

Conclusions: The VTMR might make it easier to check patients' ability to understand verbal commands than does traditional speech audiometry, in particular in those patients with poor test-taking skills.

Key Words: comprehension, hearing loss, speech audiometry.

INTRODUCTION

Speech tests used for measuring auditory processing abilities are an essential component of the audiological test battery.[1,2] Current speech audiometry methods focus mainly on the identification of words and recognition of sentences through oral repetition or by pointing them out in a written list.[3-5] Speech word lists have frequently been used in clinical settings to measure the speech reception threshold (SRT) because they are fast and easy, but there is a risk of familiarization and learning effects.[6] In order to avoid these limitations, sentence materials can be used to measure SRTs.[6] Since 1947, researchers worldwide have developed a large variety of speech perception tests using sentence materials as stimuli.[7,8] Sentence testing was designed to evaluate a subject's ability to hear and understand everyday speech, and various tests have been developed that use sentences as test items[6,9] because they are a more realistic stimulus for the examination of fluent speech perception.[10] In speech therapy and in psycholinguistic analysis, there are many psychometric instruments that are used to define speech perception and comprehension by measuring the receptive spoken vocabulary, grammar, and syntax, but these are not designed for audiological assessment.[11] However, several authors have suggested that the development of further tests to quantify the cognitive factors involved in speech and language processing may help to account for the variance in speech recognition noted across listeners.[12,13]

As far as we know, there are no speech tests in which speech comprehension soliciting the execution of simple tasks is tested by a motor response to phonetically balanced verbal commands recorded on a CD, thus allowing a psychometric function related to intensity. The execution of motor tasks is easier and less conditioned by knowledge, word fluency, and cognitive factors than is the execution of the verbal tasks (words, sentences) required by traditional speech audiometry. Furthermore, sentence recognition involves complex cognitive skills and is affected by the linguistic context,[14-16] by the patient's knowledge, and by the patient's age.[17-20] Therefore, a speech test using motor responses might make it easier to test speech perception in particular cases, such as in subjects with cognitive impairments. These subjects might have poor test outcomes on traditional speech audiometry because of poor cognitive skills rather than poor auditory function.[20] The aim of this technical note is to propose a new speech audiometry test using motor responses, to describe its construction in the Italian and English languages, and to show the preliminary results of the Italian ver-

From the Dipartimento di Scienze Chirurgiche Specialistiche, Università degli Studi di Milano (Di Berardino, Cesarani), and the Audiology Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico (Forti, Cesarani), Milan, Italy.

Correspondence: Federica Di Berardino, MD, PhD, Viale Piceno 14, 20129 Milan, Italy; e-mail: federica.diberardino@unimi.it.

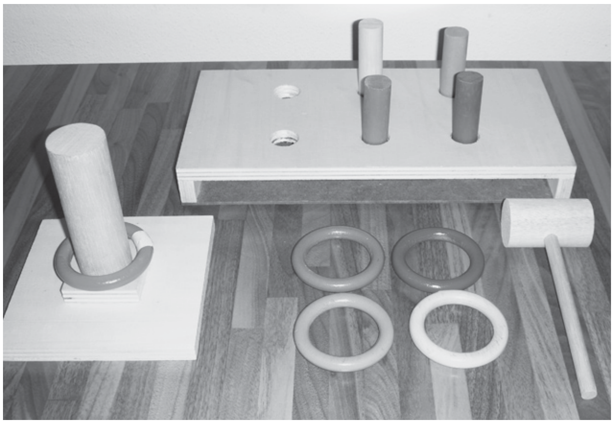

Fig 1. Setting of verbal tasks and motor responses test (VTMR).

sion in a pilot study carried out on normal-hearing and hearing-impaired subjects and on normal-hearing subjects with cognitive impairment.

METHODS

TEST MATERIALS

Figure 1 shows the items of different colors chosen according to spectroacoustic analysis in 2 different languages (English and Italian). The objects included 5 rings, 1 base, 1 hammer, and 1 wooden structure with 4 different-color sticks.[21] Tests could be performed with earphones, with the test material presented into one or both ears, or in free-field mode with suitable loudspeakers. In this case, a CD player, a speech audiometer, and 2 loudspeakers were placed at a distance of 1 m from the testing area.

A total of 20 lists with 5 verbal tasks per list (see Appendix) were compiled. These lists were standardized in terms of color type and spectral frequency pattern, and each list contained the same 5 motor tasks. They were recorded on a CD with a pause of 8 seconds between consecutive verbal tasks.

TEST STRUCTURING

Frequency Analysis. We first assessed colors and objects. Colors, names of objects, and verbal tasks were chosen to reflect the normal range of speech frequencies both in English and in Italian. The test included a set of well-known objects and simple tasks that could be performed easily in a small soundproof room. In Italian, the words for "red" and "orange" ("*rosso*" and "*arancione*") had high-frequency components; those for "blue" and "green" ("*blu*" and "*verde*") had a low-frequency pattern; and "yellow" ("*giallo*") had a uniform frequency distribution. The frequency analysis of colors in English showed that high frequencies were predominant in "green" and "yellow"; low frequencies were expressed in "red" and "blue"; and "orange" had a balancing function caused by its uniform frequency distribution. In the test (considering all 20 lists), "blue," "red," "yellow," and "green" were included 25 times. Since the Italian word for "orange" ("*arancione*") has a greater representation of higher frequencies, it was included fewer times (20 times instead of 25). In order to maintain the same motor commands in each list, we included an orange ring, but not an orange stick in the wooden structure. Each list contained all 5 chosen colors and started with a different task than the one required in the previous list. For the objects, the Italian words for "ring" and "wood" ("*anello*" and "*legno*," respectively) were chosen because of their similar frequency spectra. When we assessed whether the chosen objects could also be suitable in English, unlike the colors, which maintained a balanced frequency pattern (2 colors for higher frequency, 2 for lower, and 1 balanced), we found a difference between "ring" and "stick." In particular, "stick" had a higher frequency pattern, and "ring" had predominantly lower frequencies. To keep a spectrum-acoustic balance among the lists, we used "ring" and "stick" an equal number of times (3 times in every list of 5 commands) in order to have an equal number of low and high frequencies in each list. When the spectral analyses of the recorded Italian (black) and English (gray) versions (Fig 2) were

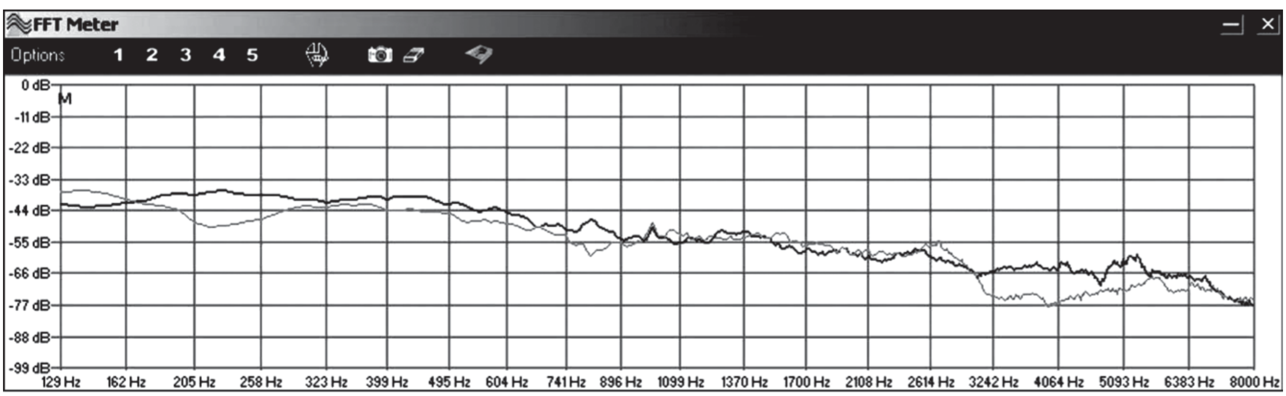

Fig 2. Spectroacoustic analyses of English (gray) and Italian (black) materials.

compared, we found that they were superimposed, with a slight prevalence of high frequencies in the Italian version, even though the word "orange" was used fewer times.

Lexical and Syntactic Analysis. After spectral acoustic analysis of the chosen words in Italian and English, 5 Italian and 5 English native speakers were asked to score each word and the whole sentences for difficulty of comprehension on a 5-point scale (5 = "easy," 1 = "difficult"). Each word and sentence received a mean rating of at least 4, and none were awarded less than 3 points. The "verb-object" structure was the preferred structure for giving a simple command and maintaining the same syntax among lists.

Formation and Equalization of Sentences. From 960 verbal tasks with different combinations of colors and objects, a total of 100 sentences were selected to have the same motor execution difficulty, color types, and spectral frequency pattern in every list of 5 commands. Each list required the same 5 tasks to be carried out with different colors in different orders. We excluded lists that employed the same color more than 3 times. Each list started with a task different from the previous one, and the 5 tasks were never proposed in the same order in consecutive lists. All of these criteria reduced the possible combinations to 62. From this pool, we randomly chose 20 lists of 5 sentences each, with "orange" included 20 times and the other colors 25 times, according to the spectral analyses.

Spectral-Acoustic Analysis. Fast Fourier analysis of the chosen lists (amplitude and intensity related to time) was performed from 125 to 8,000 Hz at a 48-kHz frequency sample (the most precise rate) with a Hamming filter by WaveLab 6.0 and SpeechLab Recognition software. The amplitudes were analyzed for statistical differences by means of the Kruskal Wallis test for unpaired data, because the data were not distributed normally. The Mann-Whitney test was used as a post hoc test. No statistically significant differences were found ($p > 0.05$). For the acoustic spectral analysis of the lists, a 1-way analysis of variance for repeated measure was used. No significant differences were found in the 20 lists ($p > 0.05$, variance analysis, SPSS 13.0). All spectral acoustic analyses were performed for both the Italian and English versions.

CD Recordings. The vocal material was recorded in a professional recording studio with a TLM 103 Neumann microphone connected to a digital audio station with floating point type. The signal was digitized with a 44.1-kHz sampling frequency at 16–bits per channel quantization. To preserve the natural sound of the human voice, which would be lost in a simple digital recording, we preamplified the signal with an API preamplifier and then processed it with a solid-state device. WaveLab 6.0 software was used in the digital audio station to collect and process the speech sounds. The recording procedure did not use compression in the speech range in order to avoid possible distortions of the vocal dynamics; therefore, natural sound was maintained. The vocal material was recorded on a CD with a 44.1-kHz sampling frequency and 16–bits per channel quantization with a professional CD rewritable recorder.

The speakers were native (UK) English and Italian male professionals, chosen by an experienced speech pathologist after a voice spectral analysis. They were trained to read the materials before the final recording. During the recording, they were seated in a sound-treated room according to UNI EN ISO 8252-2.[22] They were asked to pronounce the words as clearly and naturally as possible, and to maintain the intensity of their speech sounds at a constant level. The sound engineer monitored the sound level and recorded the material using the audio station. The level of ambient noise was 25 dBA, measured with a sound-level meter.

A total of 20 text lists were recorded in a single track on a CD. Each list was preceded by an acoustic signal. Cocktail-party background noise was recorded on the other stereo channel. The mean output of all of the recorded materials was set to 60 dB SPL (sound pressure level; root mean square) with peak variations of less than ±3 dB SPL. The CD recording started with a calibration tone (60–dB SPL, 1-kHz pure tone) that lasted 30 seconds in stereo mode.[23]

Calibration Procedure. The audiometer, or Vu-Meter, was set at 0 Vu, and the audiometer potentiometer was set at 60 dB SPL. The earphone output was 60 dB SPL and was measured with a sound level meter microphone kept 1 cm from the earphone, according to UNI EN ISO 8253-3.[24]

PILOT STUDY

The Italian version of the speech audiometry test using verbal tasks and motor responses (VTMR) was evaluated in 15 volunteers with normal hearing (mean age, 38.65 ± 18.21 years; 9 men and 6 women). None had a history of vertigo, balance disorders, hearing loss, or otological problems, and their results were normal on otological evaluation (by otomicroscopy) and audiological evaluation (by pure tone audiometry and immittance audiometry). Their hearing thresholds were 20 dB hearing level (HL) or better at all octave frequencies between

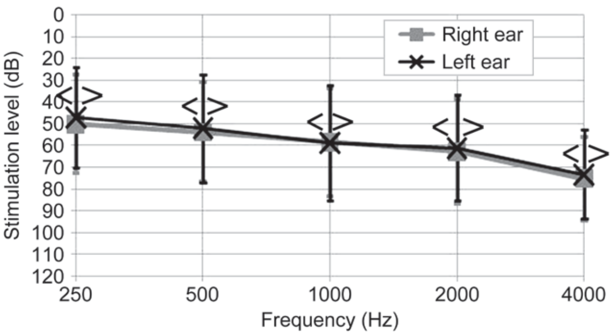

Fig 3. Mean (and standard deviation) audiogram of subjects with hearing loss.

125 and 8,000 Hz (mean threshold between 500 and 4,000 Hz ± SD, 10.33 ± 2.75 dB HL for the right ear and 10.56 ± 2.86 dB HL for the left ear). We had all subjects repeat each test 3 times once a week for 3 weeks in order to assess the possible presence of learning and practice effects.

The Italian version of the VTMR was also performed by 16 subjects (mean age, 63.4 ± 20.11 years; 5 men and 11 women) who had isolated sensorineural hearing loss according to the guidelines of the American Academy of Otolaryngology.[25] Their auditory thresholds were 56 ± 26.30 dB HL in the right ear and 56 ± 32.49 dB HL in the left ear (Fig 3).

Finally, the Italian version of the VTMR was also performed by 10 subjects (mean age, 22.3 ± 10.28 years; 6 men and 4 women) with Down syndrome confirmed by DNA analysis (trisomy 21: 47,XY,+21 or 47,XX,+21). All subjects were totally cooperative and had normal hearing; their auditory thresholds were 19 ± 4.00 dB HL in the right ear and 17 ± 4.33 dB HL in the left ear.

The VTMR results were compared to the results of traditional speech audiometry with bisyllabic words.[26] The traditional speech audiometry with bisyllabic words created by Bocca and Pellegrini[3] is a standardized method designed to test verbal recognition of words. Twenty lists of 10 bisyllabic Italian words were recorded on a CD, and the calibration tone was 1,000 Hz for 30 seconds as for the VTMR.[27] The speech materials were presented through loudspeakers in a sound-field environment (background noise lower than 45 dB SPL) on a sound system with an audiometer (Amplaid A177 plus, Amplifon, Milan, Italy), according to ANSI S3.6 2004. Both tests were initially performed at different intensities in quiet conditions, with the intensity increased by 5 dB (ascending method).

A Wilcoxon rank-signed exact test (2-tailed) was used to assess differences between the VTMR and bisyllabic speech audiometry results. The correlations between them were defined with Pearson's index. A p value of less than 0.05 was considered significant. All statistics were calculated with the Statistical Package for the Social Sciences 17.0 for Windows software package (SPSS Inc, Chicago, Illinois).

RESULTS

Figure 4A shows the mean results of the two different Italian speech tests in normal-hearing subjects. All subjects performed the VTMR and bisyllabic speech audiometry tasks (100%) correctly at 35 and 40 dB SPL, respectively. All of the retests of the VTMR produced the same results in each subject.

The Table shows the mean percentage of correct answers per intensity in quiet conditions (sound-field environment) in the patients with sensorineural hearing loss. Above 50 dB SPL (close to their auditory thresholds), the percentage of correct answers was significantly higher for the VTMR. Pearson's indices indicated significant correlations between the VTMR and bisyllabic speech audiometry results, but only for intensities greater than 60 dB. In particular, the correlation scores were 0.585 at 60 dB ($p = 0.022$), 0.766 at 70 dB ($p = 0.001$), 0.845 at 80 dB ($p < 0.001$), and 0.567 at 90 dB ($p = 0.034$).

Figure 4B shows the mean results of the two different Italian speech tests in the normal-hearing subjects with Down syndrome, and the Table reports the

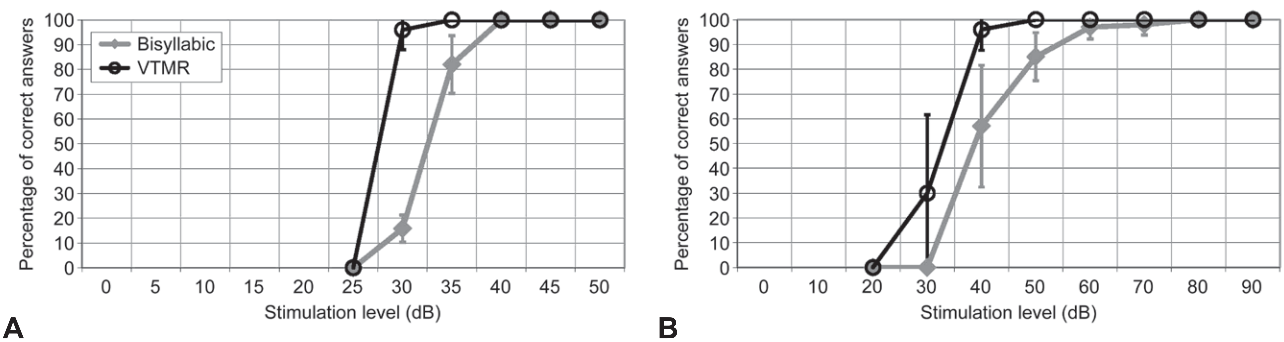

Fig 4. Mean (and standard deviation) recognition percentage for normal-hearing subjects **A)** without and **B)** with Down syndrome for VTMR and traditional speech test with bisyllabic words (Italian versions).

PERCENTAGES (MEAN ± SD) OF CORRECT RESPONSES IN TWO TYPES OF SPEECH AUDIOMETRY

Stimulation Frequency (dB SPL)	*Speech Audiometry With Verbal Tasks and Motor Responses*	*Bisyllabic Speech Audiometry*	*p (2-Tailed Wilcoxon Exact Test)*
Subjects with isolated sensorineural hearing loss			
30	12.00 ± 25.97	0 ± 0	ns
40	32.00 ± 44.59	6.67 ± 25.82	ns
50	57.33 ± 46.51	19.33 ± 35.95	0.004
60	73.33 ± 45.77	42.67 ± 42.84	0.006
70	80.00 ± 41.40	60.00 ± 40.53	0.008
80	86.67 ± 29.92	69.33 ± 39.18	0.008
90	93.33 ± 25.82	70.00 ± 35.51	0.016
Normal-hearing subjects with Down syndrome			
30	30.00 ± 31.62	0 ± 0	0.031
40	96.00 ± 8.43	57.00 ± 24.52	0.002
50	100.00 ± 0.00	85.00 ± 9.72	0.008
60	100.00 ± 0.00	97.00 ± 4.83	ns
70	100.00 ± 0.00	98.00 ± 4.22	ns
80	100.00 ± 0.00	100.00 ± 0.00	ns
90	100.00 ± 0.00	100.00 ± 0.00	ns

SPL — sound pressure level; ns — not significant.

mean percentage of correct answers per intensity in quiet conditions (sound-field environment) in the normal-hearing subjects with Down syndrome. All subjects performed the VTMR and bisyllabic speech audiometry tasks (100%) correctly at 50 and 80 dB SPL, respectively.

DISCUSSION

Even though the validity and reliability of speech recognition testing can be influenced by several factors, such as familiarity with and the phonetic balance of words, the length of the test list, or the method and level of presentation,[14-16] speech tests are generally regarded as more clinically acceptable than pure tone audiometry for identifying patients with poor auditory analytic capabilities, because speech tests involve the assessment of higher-level linguistic activities and the effects of contextual constraints in processing auditory information.[28] Furthermore, to evaluate the ability of a subject to hear and understand everyday speech, various tests have been developed with sentences as test items.[7] Speech tests with sentences are partially affected by patients' knowledge and age. To solve these limitations, the VTMR uses relatively easy items and words. Audiological assessment using speech tests is also useful for evaluating the comprehension of patients affected by hearing loss. When given with background noise, speech tests aid the verification of hearing aids and determine the patient's relative ability to hear in noise.[29] The aim of the VTMR is to add motor task execution to the speech comprehension evaluation. The "sentence processing network" still remains largely to be understood, particularly in terms of the neural circuits involved in higher-level aspects of language processing (sentence-level and grammatical processes) and in terms of the neural computations that are carried out at all stages of processing. Carrying out various motor tasks is minimally conditioned by knowledge, word fluency, and morphosyntactic processing.[30] Furthermore, it is well known that the hand motor system is activated by linguistic tasks, and not by auditory or visuospatial processing[31]; therefore, we chose tasks involving the use of the upper limbs.

Using a closed set of familiar objects whose function is intrinsic to the objects, the VTMR commands have an elevated redundancy and, therefore, place emphasis on cognitive factors involved in speech and language processing. Furthermore, using sentences rather than words gives better scores due to the presence of lexical, semantic, and syntactic redundancies, dynamic cues, and the opportunity to use compensatory strategies.[32] Another advantage of the VTMR is that it can be administered in a relatively short time.

The decision to use easy tasks with familiar words in the VTMR lists was made in order to positively affect patient performance and the overall reliability of the test.[33,34] This characteristic allows the VTMR to be less influenced by the listener's level of education.[35] However, it also increases the number of clues available to the listener and reduces the dependence of the VTMR responses on the discrimination capacity.[36] Therefore, the higher redundancy of the VTMR is a possible disadvantage of the test, since it may be less discriminating than traditional bisyllabic word testing. The lack of discrimination capacity was evidenced by the fact that the VTMR performance-intensity curves were straighter than those obtained with the traditional bisyllabic test in all of the groups in the pilot study.

The lists were read by native English and Italian male professional speakers, since recordings in a non-native accent may significantly reduce performance, especially at presentation levels of 50 dB SPL.[37] One limitation of our research was that the pilot study was carried out only in Italian. Nevertheless, we have also reported the English VTMR lists in order to prompt the validation of our English version by native English-speaking researchers. As expected, there were no differences in normal-hearing subjects between the VTMR and bisyllabic speech test results, probably because of a ceiling effect. However, in patients with peripheral sensorineural hearing loss, the VTMR responses were significantly better than those obtained with the traditional bisyllabic speech test. The VTMR's high signal redundancy, in fact, showed that these patients with peripheral sensorineural hearing loss did not have any cognitive impairment that could affect speech recognition.

The lack of correlation between the VTMR and bisyllabic speech test scores at a lower intensity of stimulation is due to a higher variability of data at values closer to background noise levels (30 dB SPL). The correlation gradually increased when the presentation level was increased from 60 to 80 dB SPL, but it decreased at 90 dB SPL. This reduction could be due to the fact that most of the patients reached 100% correct responses to the VTMR at 80 dB SPL and maintained this score at 90 dB SPL, while the number of correct responses to bisyllabic words continued to grow, thus causing a reduction in the space between the two curves. In normal-hearing subjects (with or without cognitive impairment), it was impossible to calculate the correlation between the VTMR and bisyllabic test scores because at almost all intensities, either one or the other was constant. In its simplicity and redundancy, the VTMR might make it easier to check the ability to understand verbal commands, in particular in those patients with poor test-taking skills or minor compliance, those requiring more repetitive items, and those who do not respond well to traditional speech tests, such as the elderly,[20] children with auditory processing disorders,[38] and subjects with cognitive impairments.[20] The preliminary results obtained in normal-hearing subjects with Down syndrome confirmed this hypothesis, giving significantly better scores on the VTMR at lower intensities. However, in order to facilitate compliance with the tests and their reliability, all subjects with poor cognitive skills had normal hearing and were totally cooperative, thus obtaining excellent responses at higher intensities on both speech tests.

The VTMR should be a valuable preliminary complementary tool for the assessment of speech comprehension. Further studies are needed to confirm this hypothesis and to evaluate the clinical effectiveness of the VTMR in different types of patients with poor test-taking skills.

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See Appendix on next page.

APPENDIX

ENGLISH VERSION OF THE VTMR TEST

1 with the hammer, hit on the green stick once
take the orange ring off the base
pick up the yellow ring
with the hammer, hit on the blue stick once and on the yellow stick once
put the green ring onto the base

2 with the hammer, hit on the yellow stick once and on the red stick once
pick up the red ring
take the green ring off the base
put the red ring onto the base
with the hammer, hit on the blue stick once

3 pick up the orange ring
with the hammer, hit on the yellow stick once
take the red ring off the base
with the hammer, hit on the blue stick once and on the green stick once
put the yellow ring onto the base

4 pick up the orange ring
take the yellow ring off the base
with the hammer, hit on the red stick once and on the green stick once
put the orange ring onto the base
with the hammer, hit on the blue stick once

5 pick up the green ring
with the hammer, hit on the yellow stick once
take the orange ring off the base
with the hammer, hit on the blue stick once and on the green stick once
put the yellow ring onto the base

6 with the hammer, hit on the green stick once
take the yellow ring off the base
pick up the orange ring
put the red ring onto the base
with the hammer, hit on the blue stick once and on the red stick once

7 pick up the green ring
with the hammer, hit on the blue stick once and on the green stick once
take the red ring off the base
with the hammer, hit on the yellow stick once
put the yellow ring onto the base

8 with the hammer, hit on the blue stick once
take the yellow ring off the base
pick up the red ring
put the orange ring onto the base
with the hammer, hit on the red stick once and on the green stick once

9 take the orange ring off the base
with the hammer, hit on the red stick once
pick up the blue ring
with the hammer, hit on the blue stick once and on the green stick once
put the yellow ring onto the base

10 pick up the green ring
with the hammer, hit on the red stick once
take the yellow ring off the base
with the hammer, hit on the blue stick once and on the green stick once
put the green ring onto the base

11 with the hammer, hit on the blue stick once
pick up the orange ring
take the green ring off the base
with the hammer, hit on the yellow stick once and on the red stick once
put the orange ring onto the base

12 with the hammer, hit on the blue stick once and on the red stick once
take the orange ring off the base
pick up the blue ring
put the red ring onto the base
with the hammer, hit on the yellow stick once

13 with the hammer, hit on the blue stick once
take the red ring off the base
pick up the green ring
put the blue ring onto the base
with the hammer, hit on the green stick once and on the yellow stick once

14 pick up the orange ring
with the hammer, hit on the red stick once and on the green stick once
take the blue ring off the base
with the hammer, hit on the yellow stick once
put the green ring onto the base

15 with the hammer, hit on the blue stick once and on the yellow stick once
take the green ring off the base
pick up the yellow ring
put the orange ring onto the base
with the hammer, hit on the red stick once

16 take the orange ring off the base
pick up the red ring
with the hammer, hit on the blue stick once
with the hammer, hit on the green stick once and on the yellow stick once
put the blue ring onto the base

17 with the hammer, hit on the green stick once
take the blue ring off the base
pick up the orange ring
put the red ring onto the base
with the hammer, hit on the yellow stick once and on the red stick once

18 pick up the orange ring
with the hammer, hit on the blue stick once and on the yellow stick once
take the red ring off the base
with the hammer, hit on the green stick once
put the orange ring onto the base

19 take the orange ring off the base
with the hammer, hit on the blue stick once
pick up the red ring
put the blue ring onto the base
with the hammer, hit on the yellow stick once and on the red stick once

20 pick up the orange ring
with the hammer, hit on the green stick once and on the yellow stick once
take the blue ring off the base
put the orange ring onto the base
with the hammer, hit on the red stick once