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Speech recognition performance on a modified nonsense syllable test

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Abstract—A modification of the City University of New York nonsense syllable test (CUNY NST) has been developed in which (*a*) the several subtests of the original test are replaced with a 22-item consonant-vowel (CV) subtest and a 16-item vowel-consonant (VC) subtest; and, (*b*) the response choices for each target syllable include all 22 initial and all 16 final consonants, respectively. In addition, the test tokens are presented as isolated syllables without a carrier phrase. These changes enable the resolution of confusions not possible on the original NST, and also the construction of a single confusion matrix each for CVs and VCs, respectively. The modified nonsense syllable test (MNST) provides results that compare favorably to those of the original NST.

Key words: *consonant confusions, hearing, nonsense syllables, speech discrimination, speech intelligibility, speech recognition.*

INTRODUCTION

The City University of New York (CUNY) Nonsense Syllable Test (NST) (1,2) is a closed-set speech recognition test involving the identification of consonants that are presented in a framework of meaningless consonant-vowel (CV) and vowel-consonant (VC) syllables. It was originally constructed to resolve performance differences and phoneme identification errors arising from the use of alternative hearing aid conditions. Since its introduction, the NST has been extensively documented acoustically and perceptually, and has been shown to be impressively precise and reliable (2,3,4,5). Consequently, the NST has been employed successfully in many studies dealing with both theoretical and clinical issues.

Because of its originally-intended application, the NST was designed to concentrate on the kinds of consonant confusion errors that are the *most likely* to occur (2). For this reason, the NST was constructed in the form of subtests (or subsets). Any given subset of the NST tests from seven to nine different consonants, and the possible response alternatives for a given nonsense syllable presented to the subject, are limited to the syllables in that particular subset. Specifically, the choices in a given subset include the target consonant itself and alternatives differing from the target sound in place and/or manner of articulation. Voicing confusions, however, are not included because they occur only infrequently.

As a result of this approach, the NST is able to reveal place and/or manner confusions with high resolution. On the other hand, it cannot resolve voicing errors—because these are not possible choices in the response frames—or other perceptual confusions for which the perceived consonants are not represented within the same subtest as the stimulus (6). Thus, it is conceivable that at least some measured perceptual confusions are not represented as they were heard because the perceived consonant was not among the possible choices. In addition, the results generated by the NST do not enable one to construct a single confusion matrix (one each for CVs and VCs, respectfully), because

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Table 1.
Alternatives per stimulus on the MNST in the orthographic form presented in alphabetical order for each stimulus item.*

Initial:	b ch d f g h j k l m n p r s sh t th TH v w y z
Final:	b d f g k m n ng p s sh t th TH v z

* Corresponding phonemes for the orthographic representations are: "ch" / tʃ /; "j" /dʒ/; "sh" /ʃ/; "th" (θ); "TH" (ð); "y" /j/; "ng" /ŋ/.
MNST = Modified Nonsense Syllable Test.

all possible responses are not permitted for all possible stimuli. Consequently, the usefulness of the test can be limited in situations where one is interested in a wide range of possible perceptual confusions, and/or when one confusion matrix is needed for the intended analysis.

This report describes a modification of the NST that was undertaken to overcome these limitations, while retaining the well-established overall integrity of the test. In addition, it presents initial speech recognition findings obtained with the modified test using normal hearing subjects.

METHOD

Modifications of the NST

Briefly, the modified NST was constructed as follows: Beginning with a submaster recording of the original NST (using a male talker), each CV and VC with vowel /a/ was low-pass filtered (at 10,000 Hz) and digitized (at a 25,000 Hz sample rate). The carrier phrase ("You will mark — please") was then extracted using a waveform editing program, leaving only the test syllable itself.

The carrier was omitted for two reasons. The first reason related to our principal intended use for the test in reverberation experiments. Here, we wanted to study the effects of reverberation upon the perception of the test syllables, *per se,* without contamination of the results due to temporal smearing from other utterances (i.e., the carrier phrase). The second reason was a pragmatic one—to minimize the already extensive testing time dictated by the large number of conditions and replications that typify the applications of such a test.

Each digitized nonsense syllable was then stored as an individual file. The digitally stored syllables were then randomized into test lists. Each randomized test list contained the identical tokens as any other list except, of course, that their order was different. Each initial consonant test list included 22 CVs, and each final consonant list included 16 VCs. After processing and randomization, the resulting syllable lists were recorded onto magnetic tape for testing purposes. For each stimulus token, the subjects were given a choice of all 22 CV alternatives for every syllable presented in the initial test, and with all 16 VC alternatives for each one presented in the final test. Subjects responded by marking the chosen response alternative on an answer sheet.

Table 1 shows the 22 items on the CV subtest, and the 16 tokens included in the VC subtest. These are shown orthographically in alphabetical order as on the answer sheets used by the subjects.[1]

EXPERIMENT I

Subjects

The subjects included 12 normal hearing adults who were native speakers of English with no history or complaints of neurologic or otologic problems. They included 10 females and two males ranging in age from 22 to 48 (mean 28) years. Each subject had pure tone thresholds not exceeding 10 dB HL (7) at 250-8000 Hz, and normal tympanograms and acoustic reflexes (8,9) for both ears.

Procedure

All testing was accomplished in a sound-treated room exceeding the American National Standards Institute (ANSI) S3.1 (1960), standard for audiometric environments (10). Following instructions and the administration of a practice list, the modified NST was presented to each subject monaurally through a TDH-50 earphone and supra-aural cushion at sound pressure levels (SPL) of 20, 28, 36, 44, and 52 dB. Presentation order was randomized among all of the conditions. Performance-intensity functions were obtained for the syllables presented alone (i.e., in quiet) and also in the presence of an equalized cafeteria babble at a S/N ratio of +5 dB. These levels and S/N ratios correspond to those previously reported for the original NST by Dubno and Levitt (5).

The subjects were tested individually in one or two sessions. Each subject received all of the conditions twice, and each score was based on the average of these two presentations.

[1]The process of scanning the many alternatives to choose and mark a response is an admittedly complex process for the subject. This appears to be an unavoidable problem when using tests of this type. In order to avoid errors in this study, the tester constantly monitored the stimuli and the subject's responses to assure that the subject was keeping up with the test; and the tape was stopped and/or items were repeated, as necessary. Experience suggested that keeping up with the test was not difficult for our young, normal subjects except at lowest levels where the material was barely audible.

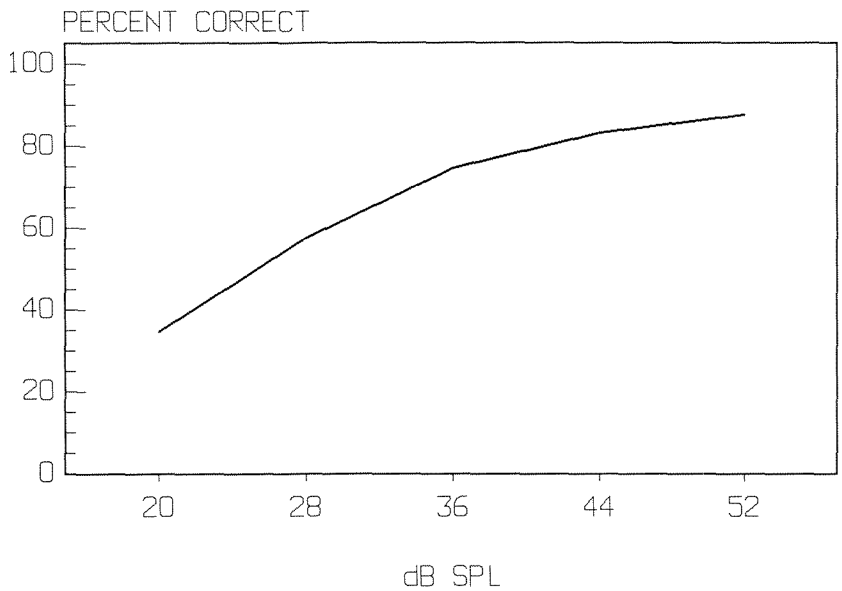

Figure 1.
Performance-intensity function for overall percent correct performance on the MNST combined across all conditions.

Results

Mean scores and standard deviations for all conditions are shown as a function of level in **Table 2**. Analysis of variance revealed that the main effects of presentation level ($p < 0.001$) and quiet-versus-noise ($p < 0.01$) were significant, as was the level-by-quiet/noise interaction ($p < 0.001$). (These and other analyses involving proportional data were accomplished with arcsine transformations to stabilize the error variance.) The main effect of initial versus final subtests was nonsignificant; but the presentation level by initial/final interaction was significant ($p < 0.01$), reflecting the fact that the small differences between initial and final scores were in opposite directions for lower and higher presentation levels.

Figure 1 shows the performance-intensity (PI) function for overall scores as a function of level in dB SPL. Percent correct scores increased at a rate of about 2.5 percent per dB up to 36 dB SPL, and 0.8 percent per dB from 36 dB to 52 dB.

Figure 2 shows percent correct performance in quiet-versus-noise as a function of presentation level, collapsed across the initial and final subtests. The solid line refers to the quiet condition and the dashed line is for syllables presented in the presence of the babble at a +5 dB S/N ratio. Percent correct scores were the same in quiet and in noise at the two lowest levels, and diverge in the expected direction for the higher levels, reflecting the aforementioned level-by-condition interaction. Percent correct scores increased at 2.5 percent per dB in quiet and 2.4 percent per dB in noise up to 36 dB SPL, and slowed between 36 to 52 dB SPL to a rate of approximately 1 percent per dB in quiet and 0.6 percent per dB in noise.

Table 2.
Percent correct means and standard deviations for all conditions in Experiment 1.

Level	(dB SPL)		20	28	36	44	52
Quiet	Initial	(Mean)	32.0	54.0	75.4	89.0	92.6
		(SD)	9.5	8.9	11.2	6.3	5.4
	Final	(Mean)	36.7	60.2	76.5	85.2	91.9
		(SD)	8.1	9.5	6.5	9.5	6.7
Noise	Initial	(Mean)	32.9	53.0	73.9	80.5	83.1
		(SD)	7.7	9.4	10.1	6.8	5.4
	Final	(Mean)	36.5	62.8	71.9	78.1	82.0
		(SD)	11.0	10.4	7.9	6.1	7.8

SD = Standard Deviation.

Discussion

This experiment has generally revealed expected findings for the modified nonsense syllable test, in the sense that the results were similar to those obtained with the original NST. The unanticipated lack of a significant CV/VC difference is addressed in the General Discussion section. Some comment is appropriate here regarding the presentation level-by-quiet/noise interaction.

Because the S/N ratio was +5 dB for all noise conditions, the babble levels were only 15 and 23 dB SPL when

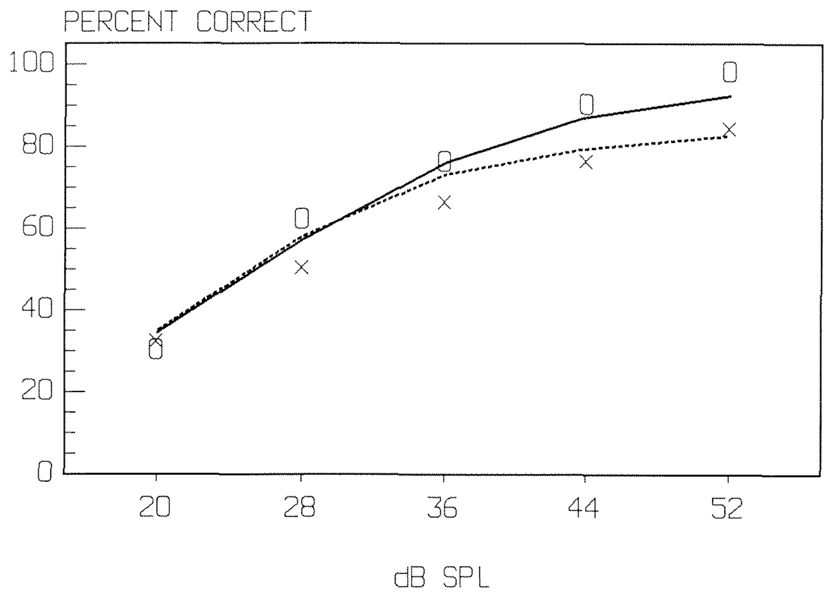

Figure 2.
Performance-intensity functions for the MNST in quiet (solid lines) and in noise (dashed lines). Corresponding data from Dubno and Levitt (5) for the original NST (quiet=O, noise=X).

the syllables were presented at 20 and 28 dB SPL, respectively. Thus, at these presentation levels the addition of the babble would yield little if any change compared to the ambient noise floor also present for the quiet condition, so that the task was effectively the same for both conditions. On the other hand, the relative contribution of the babble to the masking of the syllables would predominate over the noise floor with increasing presentation levels, so that a quiet-versus-noise effect would now become apparent. Because the S/N ratio is fixed, one might anticipate that the performance difference between the quiet and noise conditions would become essentially constant for levels above 52 dB SPL. However, this point cannot be accepted on face value because, for example, Stelmachowicz *et al.* (11), found that speech recognition scores of normal listeners differed at 60 and 80 dB SPL for monosyllabic words presented in noise.

The current findings are compared to analogous data using the original NST reported by Dubno and Levitt (5) in **Figure 2**. The original NST data are shown by circles for scores in quiet and Xs for scores in noise. Recall that the current data are based upon only the /a/-subsets, whereas the 1981 means are based upon three vowel subsets, (i.e., /i/, /a/, and /u/). The agreement between the two sets of data is impressive. The slopes of the functions for the quiet and noise conditions for the original and modified NSTs are similarly close: in quiet, the overall slope is 1.81 percent per dB for the modified NST compared to 1.93 percent per dB for the original test. In quiet, performance on the modified NST rises at an overall rate of 1.50 percent per dB, which also compares favorably with 1.57 percent per dB as reported by Dubno and Levitt (5).

These findings indicate that the stimulus modifications involved in removing the carrier phrases, and the effects of increasing the response alternatives to include all consonants represented in the test, did not appreciably affect performance on the NST.

EXPERIMENT II

The second part of the study addressed the nature of the errors made on the modified nonsense syllable test (MNST). This was done to determine what errors and confusions are to be expected on the MNST when normal listeners hear the materials at clearly audible levels. It also reveals the responses that are obtained in the absence of any experimental manipulations that might be introduced by an investigator using the test. Analyzing the responses is necessary because some differences in confusions among consonants might be expected on the modified test compared to the original NST. These differences might occur for at least two reasons. First, the number of response alternatives was expanded from the seven to nine most likely ones in the original NST to essentially all possible alternatives (22 for CVs and 16 for VCs) in the modified version. Hence, a perceived error consonant that is not among the possible choices in the original NST would necessitate a different choice as the response, whereas the consonant actually heard would more likely be a viable response on the MNST. The most obvious example would be the ability of the MNST to reveal voicing confusions not possible on the original NST. Moreover, Bell, Dirks, and Kincaid (12) recently demonstrated that confusion patterns depended upon the number of response alternatives.

The second likely reason to anticipate different errors between the NST and the MNST is that the test tokens are surrounded by a carrier phrase in the NST but are presented in isolation in the modified version. Hearing only the isolated test syllable denies to the listener an immediate frame of reference regarding the speech acoustics and timing of the talker that might be derived from being in the context of the carrier (especially for CVs). It is also possible that the editing process may have removed parts of the signal, including coarticulatory information, thereby affecting specific confusions, although this is unlikely.[2]

Subjects

There were 15 subjects in this experiment, including 14 females and one male. These subjects ranged in age from 18 to 21 (mean 24) years and met the same criteria for normality used in Experiment I.

Procedures

The materials were presented monaurally at 44 and 52 dB SPL, which were the two highest levels used in Experiment I, and where high percent correct scores were found. Testing was done at both 44 and 52 dB SPL as a compromise to achieve the somewhat conflicting goals of generating a reasonably sufficient number of errors to analyze while at the same time keeping the presentation levels high enough to reflect typical performance for when the test materials are audible and undistorted. The MNST was administered both in quiet and in the context of equalized cafeteria babble (at an S/N ratio of +5 dB) to provide typical normal results under both conditions, which are frequently used in speech recognition applications. Because 44 and 52 dB were also the levels where a performance difference was found between the quiet and noise conditions in Experiment I, testing at these levels was expected to reveal differences in errors between the quiet and noise conditions.

Table 3.
Percent correct means and standard deviations in Experiment II.

		Quiet	Noise
Initial	(Mean)	95.1	87.9
	(SD)	2.9	3.2
Final	(Mean)	92.7	84.8
	(SD)	5.0	5.9

SD = Standard Deviation.

Ten replications were administered for each condition, which is typical of experiments addressing confusion data. Thus, each subject listened to a total of 80 test lists [2 levels (44/52 dB) × 2 conditions (quiet/noise) × 2 consonant positions (CV/VC) × 10 replications]. The test lists were administered in random order over the course of several listening sessions, which varied in number according to the availability of the subjects.

All testing was done individually under the same conditions as described for Experiment I, and included familiarization and practice before data collection.

Results

Percent correct consonant recognition performance is summarized in **Table 3**. Analysis of variance revealed that performance was significantly better in quiet than in noise ($p < 0.001$) and for CVs than for VCs ($p < 0.01$). Their interaction was nonsignificant.

Stimulus-response (confusion) matrices from the data pooled across subjects were constructed for the four conditions (CVs and VCs in quiet and in noise). Such matrices depict the relationship between stimuli (or target) consonants in rows and the phonemes given as responses in columns. Thus, for the MNST these matrices involve 22×22 cells for CVs and 16×16 cells for VCs. Correct identification is revealed by cells along the diagonal, and the values in these cells are easily converted into percent correct identification scores for each consonant presented.

As expected, percent correct identification scores varied among the consonants. These data are summarized as a function manner and place of articulation (13) in **Figure 3** and **Figure 4**, respectively. The figures reveal that correct consonant recognition was nearly perfect for the semivowels, affricates and nasals; worst for the fricatives; and second poorest for the stops; it principally involved consonants with front places of articulation ($p < 0.01$).

Most of the errors on the MNST were due to the mis-

[2]The "cuts" made in the waveform editing process were almost always during silences indicated by no energy on the computer screen and verified by listening to the samples. The syllable segments within, and extracted from, the carriers were indistinguishable both visually and by listening. The only exception was the case of the CV syllable /sa/. Here, a /k/-like coloring (carried over from the word "mark" in the carrier phrase) at the onset of the /s/ could not be removed unless cuts would have been made well into the sibilant noise, and was thus retained in the digitized file for the /sa/ syllable. However, this isolated problem was of no consequence because (a) it was heard only while editing the digitized master, and was not audible on any of the test tapes; and (b) there was not even a single confusion between /s/ and /k/ for any of the subjects under any of the conditions.

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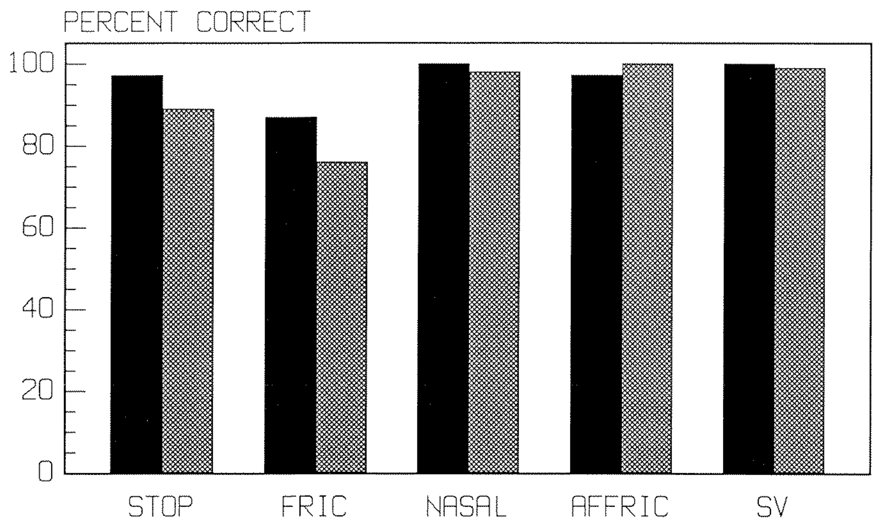

Figure 3.
Correct consonant identification in terms of manner of articulation. Solid bars show data obtained in quiet, and crosshatched bars show data in noise.

identification of a fairly small number of individual consonants. **Table 4** presents the correct identification percentages for the consonants that had scores of ≤90 percent for one or more of the four conditions, which include the most poorly recognized phonemes on the MNST. As expected from **Figure 3** and **Figure 4**, all of these consonants were fricatives or stops, and all but one (/h/) had anterior places of articulation. (Performances for /k/ fell only slightly below 90%, and this occurred for only one condition.)

The confusions that exceeded a chance rate of occurrence were determined from the confusion matrices, and are tabulated in **Table 5**. For each confusion in this table, the first phoneme is the stimulus (or target) consonant, and the second is the response given by the subjects. The confusions are expressed as percentage responses given for

Table 4.
Poorly identified consonants on the MNST and their percent correct identification scores.

Consonant	Quiet Initial	Quiet Final	Noise Initial	Noise Final	Overall
p	98.3	98.0	75.7	87.3	89.8
k	100.0	99.3	86.3	96.3	95.5
b	80.7	98.0	57.3	91.3	81.8
f	95.3	82.7	75.0	41.3	73.6
θ	89.3	52.3	76.0	47.3	66.3
v	55.0	87.0	41.0	62.7	61.4
ð	91.7	70.3	82.7	55.3	75.0
h	92.7		60.7		76.7

Table 5.
Confusions exceeding chance expressed as a percentage of the responses to the target (stimulus) consonant.

Confusions*	Initial Quiet	Initial Noise	Final Quiet	Final Noise
v b	25.3	29.7	11.3	31.7
b v	11.7	26.3		
θ f		11.3	42.0	24.3
f θ				11.0
ð d		8.0	11.7	28.7
v ð	15.3	20.7		
ð v			8.0	
f p			9.3	37.7
p f				7.7
h p	6.3	32.7		
p h		16.3		
b ð	6.0	11.7		
k h		7.0		
h k		4.7		
f v		9.7		
f b		8.7		
θ t				7.7
θ s		6.3		
p k	5.0			
g d		6.7		
tʃ ʃ	6.0			

*First consonant is the target, second is the response.

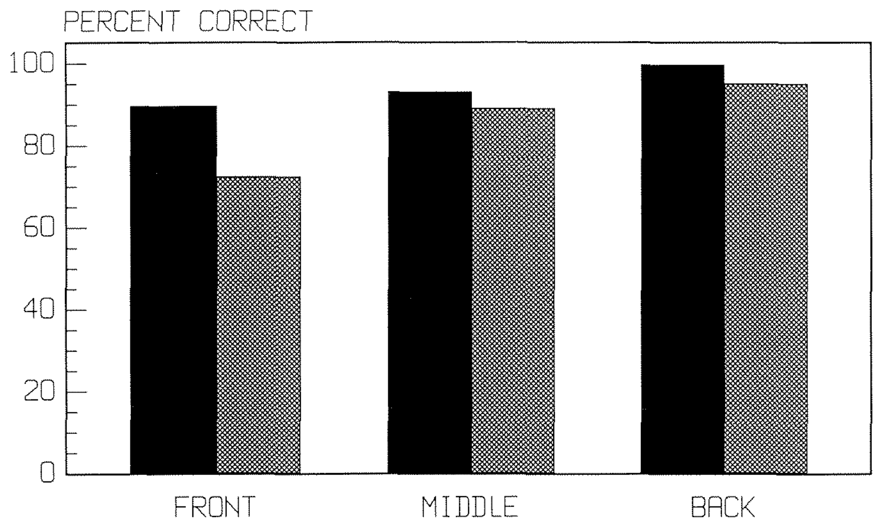

Figure 4.
Correct consonant identification in terms of place of articulation. Solid bars show data obtained in quiet, and crosshatched bars show data in noise.

Table 6.
Percentages of confusions exceeding chance involving errors of place of articulation, manner and/or voicing.

Condition		Place (P)	Manner (M)	Voicing (V)	P+M	P+M+V
Initial	Quiet	22	8		70	
	Noise	24		5	67	4
Final	Quiet	61			39	
	Noise	24			76	

that stimulus (e.g., "v b" followed by "25.3" indicates that /v/ was heard as /b/ 25.3 percent of the time). The confused pairs in this table are arranged roughly in descending order of occurrence, keeping both directions of confusions between two phonemes (e.g., /v,b/ and /b,v/) together. This table indicates that confusions were principally among consonants sharing anterior places of articulation. Furthermore, the response consonants tabulated in the table are largely consistent with the response biases of normal subjects reported for the original NST (5).

Table 6 shows the percentages of errors of specific place of articulation (e.g., bilabial, alveolar), manner, and/or voicing among confusions exceeding chance. Place-only errors predominated for VCs in quiet, but most of the confusions in the three other conditions were combined place/manner errors. Nine percent of the confusions exceeding chance for CVs in noise involved voicing errors.

Discussion

Most of the consonant identification errors involved anterior sounds, and confusions exceeding chance were principally among consonants sharing anterior places of articulation. These findings likely reflect acoustical similarities among the confused sounds (5). Most of these confusions have also been found for the corresponding subtests of the original NST (14).

Unlike the preponderance of combined place/manner errors found here for the MNST, a plurality of place errors has been reported for the original NST (5). It is unlikely that the high proportion of place/manner errors here reflects increased random guessing compared to the original test. This is so because these confusions were found among confusions exceeding chance in the current study, implying that they reflect a systematic effect.[3]

GENERAL DISCUSSION

Overall, the modified nonsense syllable test yields results comparable to those of the original NST. Several points, however, do deserve some comment.

The reason for the absence of the expected significant difference between CV and VC scores in Experiment I is unclear, particularly because the typical finding of higher CV than VC scores was observed in Experiment II. One possibility, which may explain why the VC scores were higher at 20 and 28 dB, may relate to the relative levels of the consonant and vowel portions of the syllable in the absence of a preceding carrier signal. At these low levels, the presence of the relatively more audible vowel energy may have served as a signal to attend to the consonant

[3]Actually, the proportions of place, place/manner, etc., errors found here were virtually the same regardless of whether we used all confusions or just those exceeding chance.

information in VC condition. For the CV condition, however, the attention-getting attribute of the relatively more audible vowel energy would occur too late to be used. The small difference between the CV and VC scores indicated that this effect, if actually present, is rather small. At 44 and 52 dB SPL, where the syllables were quite audible and their onsets were apparent, the small differences between initial and final scores were in the expected direction.

A possible explanation for the large representation of place/manner errors involves two facets: the first point addresses the contrast in the data obtained in quiet. Here, most of the CV confusions (70 percent) were place/manner errors, whereas the majority of VC confusions (61 percent) were place-only errors. Also, note that all place/manner confusions exceeding chance involved stop/frication errors (**Table 5**). Because the CVs were preceded by silence instead of a carrier phrase which might serve as a marker, it is possible that the perceived duration of initial position consonant noise became ambiguous, thereby increasing the number of stop/fricative confusions. The audible representations of cues for the stop/fricative distinction in the VCs would not be subject to such ambiguity, and so VC errors in quiet would be less likely to involve a manner of articulation confusion. Second, larger proportions of place/manner errors occurred for both initial and final consonants in noise. This suggests that the babble obscured manner cues, which should affect both CVs and VCs because the babble is continuously present. This point is consistent with the original NST data, where the representation of place/manner errors was much greater in noise than in the quiet condition.

In summary, a modified nonsense syllable test has been developed by replacing the multiple subtests of the original NST with a 22-item CV subtest and a 16-item VC subtest. All test items are presented as isolated syllables (i.e., without a carrier phrase). The response alternatives for each stimulus syllable encompass virtually all possible consonants in the initial and final positions, respectively. These changes make it possible to resolve confusions not possible on the original NST, and also make it possible to generate a single confusion matrix for each subtest, should one desire this capability. The modified test results in findings that compare favorably to those previously reported for the original NST. In other words, the benefits for various applications afforded by these changes do not come at the cost of compromising the already proven integrity of the NST. Therefore, one may conclude that the modified NST described here constitutes a useful tool for assessing speech recognition at the syllable level.

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