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Amplitude (vu and rms) and Temporal (msec) Measures of Two Northwestern University Auditory Test No. 6 Recordings

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Abstract

Background: In 1940, a cooperative effort by the radio networks and Bell Telephone produced the volume unit (vu) meter that has been the mainstay instrument for monitoring the level of speech signals in commercial broadcasting and research laboratories. With the use of computers, today the amplitude of signals can be quantified easily using the root mean square (rms) algorithm. Researchers had previously reported that amplitude estimates of sentences and running speech were 4.8 dB higher when measured with a vu meter than when calculated with rms. This study addresses the vu–rms relation as applied to the carrier phrase and target word paradigm used to assess word-recognition abilities, the premise being that by definition the word-recognition paradigm is a special and different case from that described previously.

Purpose: The purpose was to evaluate the vu and rms amplitude relations for the carrier phrases and target words commonly used to assess word-recognition abilities. In addition, the relations with the target words between rms level and recognition performance were examined.

Research Design: Descriptive and correlational.

Study Sample: Two recoded versions of the Northwestern University Auditory Test No. 6 were evaluated, the Auditec of St. Louis (Auditec) male speaker and the Department of Veterans Affairs (VA) female speaker.

Data Collection and Analysis: Using both visual and auditory cues from a waveform editor, the temporal onsets and offsets were defined for each carrier phrase and each target word. The rms amplitudes for those segments then were computed and expressed in decibels with reference to the maximum digitization range. The data were maintained for each of the four Northwestern University Auditory Test No. 6 word lists. Descriptive analyses were used with linear regressions used to evaluate the reliability of the measurement technique and the relation between the rms levels of the target words and recognition performances.

Results: Although there was a 1.3 dB difference between the calibration tones, the mean levels of the carrier phrases for the two recordings were −14.8 dB (Auditec) and −14.1 dB (VA) with standard deviations <1 dB. For the target words, the mean amplitudes were −19.9 dB (Auditec) and −18.3 dB (VA) with standard deviations ranging from 1.3 to 2.4 dB. The mean durations for the carrier phrases of both recordings were 593–594 msec, with the mean durations of the target words a little different, 509 msec (Auditec) and 528 msec (VA). Random relations were observed between the recognition performances and rms levels of the target words. Amplitude and temporal data for the individual words are provided.

Conclusions: The rms levels of the carrier phrases closely approximated (±1 dB) the rms levels of the calibration tones, both of which were set to 0 vu (dB). The rms levels of the target words were 5–6 dB below the levels of the carrier phrases and were substantially more variable than the levels of the carrier phrases. The relation between the rms levels of the target words and recognition performances on the words was random.

Key Words: Root mean square, speech recognition, volume unit

Abbreviations: NU-6 = Northwestern University Auditory Test No. 6; rms = root mean square; VA = Department of Veterans Affairs; vu = volume unit

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INTRODUCTION

Until digital technology became commonplace, the only standardized instrument readily available to monitor the amplitude or relative level of speech signals was an analog volume-unit (vu) meter[1] that was developed as a collaborative effort by the Columbia Broadcasting System, the National Broadcasting Company, and the Bell Telephone Laboratories (Chinn et al, 1940). Before 1940, signal amplitudes could be quantified in terms of average, root mean square (rms), and peak voltages, but there was a need by the radio broadcasting companies to express the amplitude of speech signals in a "simple numerical fashion." To meet this need, the vu meter was conceived (note: Chinn et al, 1940 and Chinn, 1951 provided detailed accounts of the development and characteristics of the vu meter). The vu meter, an example faceplate of which is shown in Figure 1, continues in common and practical usage in the broadcast and recording industries, but has been replaced on many instruments, including audiometers, by digital bar meters whose characteristics are seldom specified. Chinn et al (1940) described the detail considerations that were incorporated into the vu meter. For example, even the faceplate design received considerable attention that ranged from the length and arc of the scale, the off-vertical location of the scale reference (zero) at 71% of full scale, the scale −20 to +3 for vu divisions with the −20 to 0 divisions in black and the 0 through +3 divisions in red, the shape of the pointer or needle, and the faceplate background color (cream yellow). Many of the technical aspects of the vu meter are discussed by Lobdell and Allen (2007) in their introduction of a vu meter implemented in a software.

The vu meter, which incorporates a full-wave rectifier, has a time constant of 300 msec, and has a broadband response, is basically a mechanical averager that reflects the signal (peak) amplitudes during continuously sequential segments of time that are governed by the time constant or the ballistic characteristics of the instrument. The vu meter is most accurate measuring the amplitudes of signals with a steady-state or unmodulated envelope, like a typical sine wave. Important to this study are the sustained vowel segments of many words with steady-state envelopes and durations in the 150–350 msec range. Signals like cold-running speech or even simple sentences have substantial amplitude modulation characteristics that when measured with a vu meter produce continuous full-scale fluctuations of the measurement.

Understanding the time constant of a vu meter is critical in making measurements with the instrument. The following demonstrates the impact that the vu-meter time constant has on the vu measurement. First, the

Figure 1. The faceplate of a vu meter on the control panel of a Grason-Stadler, Model 162, speech audiometer (ca. 1969).

level of a continuous 1000-Hz tone is set to 0 vu. Then a 75 msec segment of the same 1000-Hz signal is measured. The reading on the vu meter will be something less than 0 vu because the mechanism within the vu meter did not have enough time to react completely to the brief tone, that is, by the end of the 75-msec tone, the vu meter (needle) had only reached part of the full amplitude reading (0 vu) before the tone terminated. For the same reasons, the time constant of the vu meter does not allow the vu needle to follow accurately a 75 msec gap in a continuous sinusoid. When measuring the amplitude of a speech signal whose envelope is amplitude modulated, the same phenomena occur, that is, the vu meter is unable to follow accurately the rapid amplitude fluctuations that are characteristic of a speech signal. Accordingly, the vu meter does not accurately reflect the amplitudes of brief speech signals like words that typically have short duration consonants (typically <100 msec and often much shorter [Umeda, 1977]) and few sustained vowels with durations long enough to fulfill the time constant of the vu meter. In general, vowel durations range from 150 to 350 msec (House, 1961; Umeda, 1975) and are influenced by many factors ranging from dialect (Clopper et al, 2005; Jacewicz et al, 2007) to the other utterances (mainly consonants) that precede and succeed the vowel (House and Fairbanks, 1953). With word-recognition testing, this limitation related to the time constant of the vu meter is mostly overcome by the use of a carrier phrase like, "Say the word ____" that has a fairly constant acoustic stream dominated by sustained vowels that additionally are perhaps over articulated.

Simply reading the vu meter has been the topic of several reports (see for example, Levitt and Bricker, 1970; Brady, 1971). Lobdell and Allen (2007, p. 281) suggested that "Reading a VU meter is more of an art than a science". Killion (2009) reviewed the technique that can be used to read a vu meter that we were taught years ago by Tom Tillman. This technique requires multiple visualizations of the reading (of the vu needle) with the first attempt(s) used to narrow the visual range on the meter

[1]Section 2.3 of the Institute of Radio Engineers (1954) standard states: "vu (pronounced "vee-you" and customarily written with lower case letters)" (p. 816).

to the vicinity of where the needle peaks. Then subsequent peak estimates are obtained by observing repeated peak readings as necessary that occur within this narrowed visualized range. Now, this is easily accomplished by using the "looping" playback feature available on most waveform editors. Killion estimated accuracy with this technique within <0.5 vu or dB.

Several years ago, Killion (2009) compared the calibration of speech levels using vu meter and rms measures of speech signals and calibration tones. In the course of two experiments, running speech (Ludvigsen, 1992) and the Institute of Electrical and Electronics Engineers sentences incorporated in the QuickSIN test (Killion et al, 2004) were used to compare the vu and rms levels of each material. For both types of materials, Killion reported a 4.8 dB higher level with the vu meter than with the rms measures. The contention in this report is that the carrier phrase and target word paradigm typically used with word-recognition testing is a special case that should not be expected to produce the 4.8-dB difference between vu and rms amplitudes that Killion reported with running speech and sentence materials. The reasoning here as indicated above is that the carrier phrase by design is intended to establish the level of the utterance with the presentation of the target word in a natural manner following the carrier phrase.

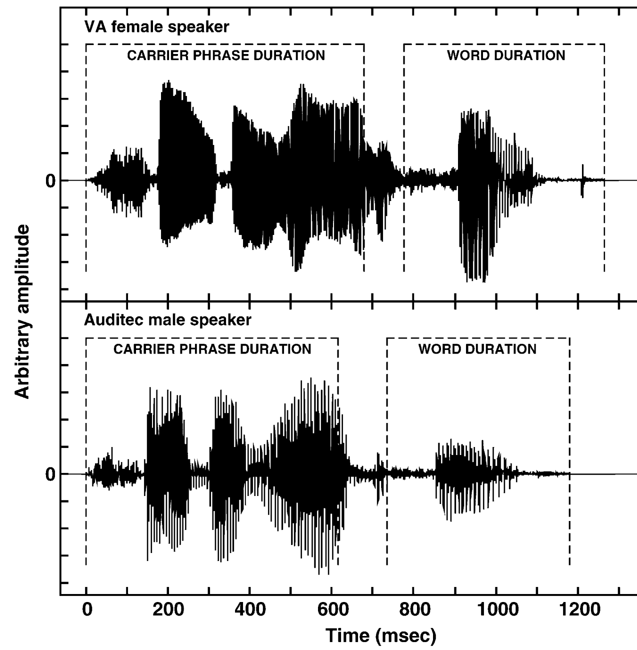

Figure 2. Waveforms of *Say the word wheat* spoken by the female and male speakers are shown. The carrier phrase and word durations used for the time and amplitude measures are defined by the dashed lines.

METHODS

The Auditec of St. Louis (male speaker) and the Department of Veterans Affairs (VA) (female speaker) recorded versions of the Northwestern University Auditory Test No. 6 (NU-6; Tillman and Carhart, 1966), which were analyzed using Adobe Audition. In compliance with the current and previous American National Standards Institute standards,[2] the individual carrier phrases of both versions of NU-6 were adjusted to 0 vu by the respective producers using the "Tillman approach." The 1000-Hz calibration tones differed on the two recordings by 1.3 dB with the VA recording having the higher amplitude. Durations of the 400 carrier phrases and target words were made in milliseconds (msec) and the rms in decibels (dB re: the maximum digitization range of the waveform editor) computed for those temporal intervals. Figure 2, which is an amplitude-by-time display of the carrier phrase and target word waveforms, illustrates the delimiters used to define the durations of the carrier phrase and target words that were made for the two versions of *Say the word wheat*.

The waveforms, which in the figure were equated in amplitude, also illustrate the similarities and differences between the utterances of the two speakers. The respective durations are close, ±100 msec, with the VA segments in this example slightly longer than the Auditec segments. Because the vu meter is especially sensitive to the peak energies in a signal, the carrier phrase duration was defined from the start of the /s/ in *say* to the end of the /or/ in *word*. The /d/ in *word* was excluded because the energy levels in /d/ were substantially below the peak energy levels of the preceding vowels in both recordings and had no influence on the peak vu readings. In addition, in many cases, the /d/ often was elongated >100 msec at reduced levels below the vowel peaks, which would artificially reduce the rms of the carrier phrase. The durations of the target words were defined from the onset of the initial consonant to the offset of the final consonant. Both visual and auditory cues were used to make these, sometimes tenuous, onset and offset decisions. The most difficult offsets to define were words whose energy tailed-off seemingly forever (e.g., /f/, /l/, /m/, /n/, and /v/).

Figure 3 presents the waveform for *Say the word keen*, again spoken by the two speakers. In this and the two subsequent figures, the shaded rectangle represents the amplitudes of the accompanying two calibration tones that were equated for these examples. Although there are brief segments of the carrier phrase that have higher amplitudes than the amplitudes of the calibration tones, in these graphic examples both the calibration tones and the carrier phrases peaked to 0 vu. Two other relations

[2]For the purpose of this standard, the sound pressure level of a speech signal is defined as the level of the rms sound pressure of a 1000 Hz signal adjusted so that the deflection of the volume level indicator produced by the 1000 Hz signal is equal to the average peak deflection produced by the speech signal. The level indicated by the monitoring meter for a preliminary carrier phrase may be taken as the level indication of the speech material following when the material is delivered in a natural manner at the same communication level as the carrier phrase (ANSI, 2010, p. 18).

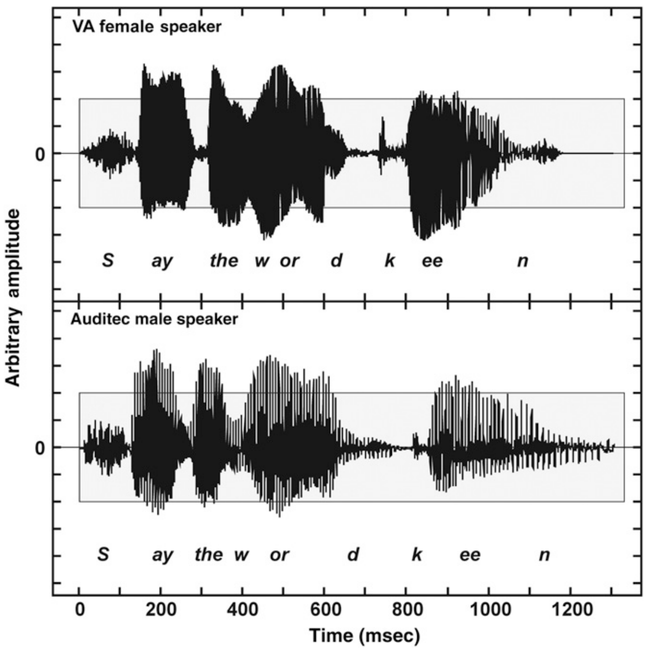

Figure 3. Waveforms of *Say the word keen* spoken by the female and male speakers are shown. The shaded rectangle reflects the amplitude of the 1000-Hz calibration tone.

in Figure 3 deserve mention. First, the male utterance is noticeably longer than the female utterance, which is in contrast to the temporal durations observed in Figure 2. Second, the amplitude asymmetries of the waveforms are apparent in Figure 3, especially for the target words spoken by both speakers. *Keen* spoken by the VA female speaker has a noticeably larger amplitude below zero than above zero but the difference between the positive and negative amplitudes for the target word was only about 0.5 dB. In contrast to the VA speaker, *keen* spoken by the Auditec male speaker has a larger amplitude above zero than below zero with the positive and negative amplitudes having a 1.5 dB difference.

The differences in waveform symmetry, which mistakenly at times have been attributed to a DC offset,[3] are often observed and are attributable to two phenomena, both of which occur naturally. The first phenomenon is mathematical. With a complex signal like speech, there are constantly changing interactions in the phase domain among the fundamental frequency and the various vocal even harmonics that produce asymmetry in the waveform. Depending on the amplitudes and phases of the various frequencies involved, the amplitude asymmetry can be larger on either side of zero. The second phenomenon is physical and is related to the fact that when we speak the movement of the air stream is in one direction, outward, which produces a positive air–pressure bias, meaning there is more energy on the positive or compression part of the modulation cycle than on the rarefaction part of the cycle. The interaction of these two phenomena determine the characteristics of the amplitude asymmetries often observed with speech waveforms and waveforms from other sources like musical instruments (D'Cunha, 2013).

Figure 4 depicts two waveforms selected to illustrate the materials spoken by the female speaker, *Say the word limb* and *Say the word pool*. Similarly, Figure 5 presents two waveforms spoken by the male speaker, *Say the word base* and *Say the word chair*. From these examples, the diversity of waveforms is apparent even when the utterances are spoken by the same speaker.

The rms levels of the various segments were computed using the "Total rms amplitude" routine in Adobe Audition. Audition computes a "Total rms amplitude" and an "Average rms amplitude" that have received ample attention on the Internet as Adobe has not exactly been forthcoming about their computational algorithms. The values of one of the waveforms (PCM format) were saved as a text file (the earlier versions of Audition could generate text files) and input into a Microsoft Excel file from which the rms was calculated. The Excel rms was the same as the Audition "Total rms amplitude," which was used in all subsequent rms measures.

RESULTS AND DISCUSSION

The reliability of the temporal and amplitude measures by the same evaluator (RH Wilson) was conducted on different days with the Auditec version of

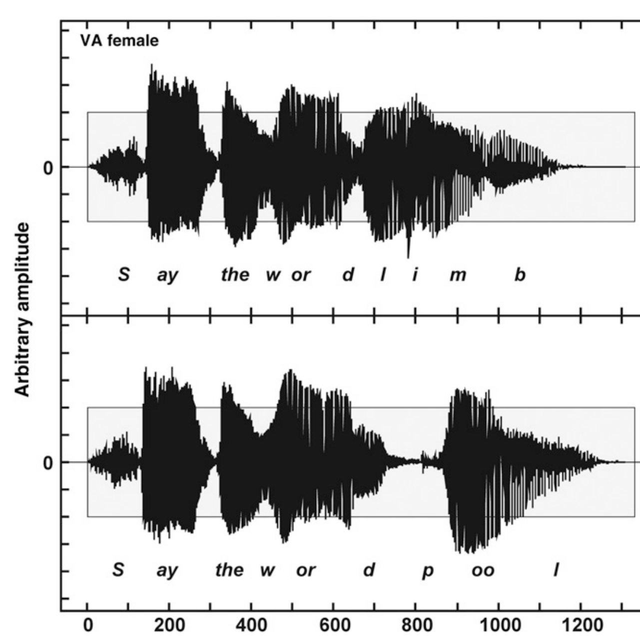

Figure 4. Waveforms of *Say the word limb* (top) and *Say the word pool* (bottom) spoken by the female speaker is shown. The shaded rectangle reflects the amplitude of the 1000-Hz calibration tone.

[3]If a DC shift were involved, then the entire waveform would be shifted by the amount of the DC component.

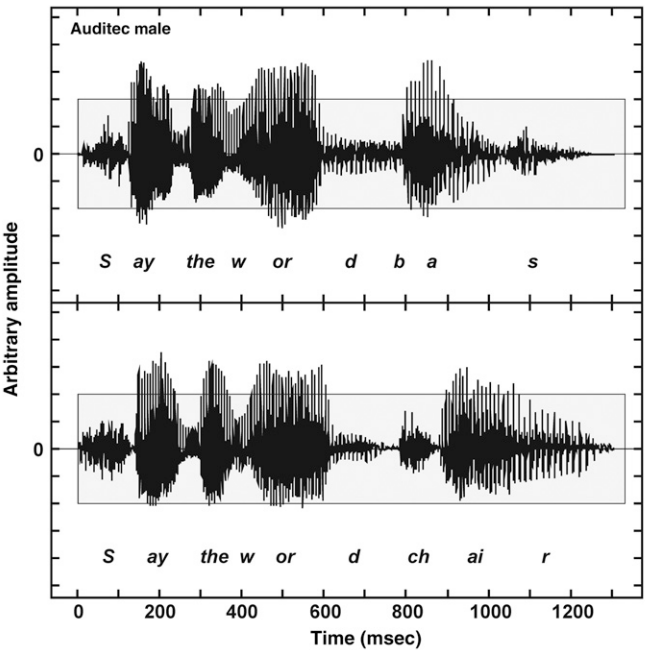

Figure 5. Waveforms of *Say the word base* (top) and *Say the word chair* (bottom) spoken by the male speaker is shown. The shaded rectangle reflects the amplitude of the 1000-Hz calibration tone.

NU-6, List 1. The results of these two measures on the carrier phrases are depicted as a bivariate plot in Figure 6. The linear regression used to describe the data in the figure has a slope of unity ($m = 1.002$ msec/msec) and an R^2 of 0.99, meaning that the two measures were essentially identical. Interestingly, the mean durations for the carrier phrases were 551.6 and 549.0 for the two estimates, which

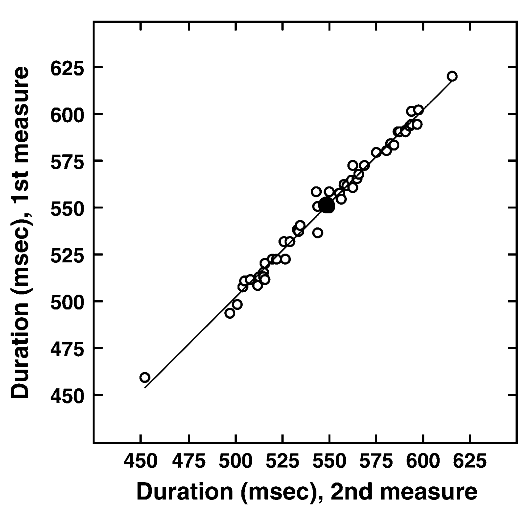

Figure 6. The durations of the 50 NU-6, List 1 carrier phrases spoken by the Auditec male speaker are shown for the first (ordinate) and second (abscissa) measures. The large, filled circle represents the means, and the solid line is the linear regression used to describe the data.

was a statistically significant difference but not of any practicality [$t_{(49)} = 4.3, p < 0.001$]. The two mean rms values of the carrier phrases (both −14.53 dB) were not significantly different [$t_{(49)} = 0.03, p > 0.05$]. These results indicate that the measurement techniques were reliable.

The descriptive statistics for the carrier phrase and target word durations and amplitudes are listed in Table 1 for the two recorded versions of NU-6. Consider the durations first. Overall, the carrier phrase means for the two speakers are essentially identical (593–594 msec) with the target word durations for both speakers being 85 msec (Auditec) and 65 msec (VA) shorter than the carrier phrase durations. In all probability, the words were recorded sequentially from List 1 through List 4, which is reflected in the mean durations for the four lists. The Auditec speaker spoke the first list somewhat faster (50 msec) than the other three lists, which may be reflecting the so-called "recording rhythm" becoming established. In contrast, the VA speaker spoke List 4 somewhat slower than the first three lists, perhaps reflecting a slight fatigue at the end of the recording session.

The amplitudes of the carrier phrases and target words were measured in rms (dB, re: the maximum digitization range of the waveform editor), hence their negative values. The rms values of the two respective 1000-Hz calibration tones were −15.3 dB (Auditec) and −14.0 dB (VA), which simply indicates that on the recording medium the amplitudes of the VA materials were 1.3 dB higher than the amplitudes of the Auditec materials. In Table 1, the mean overall rms levels of the carrier phrases were −14.8 dB (Auditec) and −14.1 dB (VA) both of which are reflected accurately by the levels of the respective calibration tones. Among the four lists, the mean rms amplitudes of the carrier phrases vary 1.2 dB and 0.4 dB for the Auditec and VA speakers, respectively. These relations among the rms levels of the calibration tones and the carrier phrases confirm the original contention that when the levels of the calibration tone and carrier phrases were set to the same vu level, the rms levels also would be similar, which is strictly owing to the unique amplitude characteristics of the carrier phrases. As was demonstrated in Figures 3–5, the amplitudes of the carrier phrases were modulated slightly above and below the constant envelope of the calibration tones, thereby producing rms carrier phrase amplitudes that essentially were equivalent to the rms amplitudes of the calibration tones. The mean amplitudes of the target words have similar variations in Table 1, 1.4 dB and 0.6 dB for the Auditec and VA speakers, respectively. Overall for the Auditec and VA speakers, the amplitudes of the carrier phrases were 5.1 dB and 4.2 dB, respectively, higher than the amplitudes of the target words.

The various amplitude relations from the rms measures are illustrated for the 200 individual words in Figure 7 (VA speaker) and Figure 8 (Auditec speaker) with the numeric

Table 1. The Temporal and Amplitude Descriptive Data for the Carrier Phrase and Target Words That Were Obtained for the Auditec and VA Recordings of the Four NU-6 Lists and for the Four Lists Combined (Overall)

	Auditec Recordings				VA Recordings			
	Carrier Phrase		Target Word		Carrier Phrase		Target Word	
	msec	rms (dB)	msec	rms (dB)	msec	rms (dB)	msec	rms (dB)
Means								
List 1	551.6	−14.5	513.4	−19.7	598.1	−13.9	553.3	−18.6
List 2	600.8	−15.3	495.3	−20.5	559.4	−14.0	512.8	−18.0
List 3	607.6	−14.2	502.1	−19.1	579.2	−14.2	511.3	−18.1
List 4	612.2	−15.4	523.6	−20.3	638.7	−14.3	535.9	−18.2
Overall	593.0	−14.8	508.6	−19.9	593.9	−14.1	528.3	−18.2
Standard Deviations								
List 1	34.9	0.5	93.4	1.3	37.6	0.3	70.4	1.9
List 2	33.3	0.6	104.3	1.5	38.3	0.5	67.7	1.5
List 3	33.7	0.7	76.7	1.3	27.1	0.5	62.7	1.3
List 4	36.0	0.5	76.3	2.0	24.9	0.4	72.8	1.9
Overall	42.0	0.8	88.5	1.6	43.6	0.5	70.2	1.7
Maxima								
List 1	621	−13.4	698	−17.4	716	−12.8	701	−13.5
List 2	691	−14.1	663	−18.1	661	−13.1	640	−14.5
List 3	665	−12.6	662	−15.9	644	−12.8	679	−14.9
List 4	684	−14.0	677	−16.7	705	−13.3	652	−13.8
Overall	691	−12.6	698	−15.9	716	−12.8	701	−13.5
Minina								
List 1	460	−15.7	311	−23.8	537	−14.6	366	−22.3
List 2	534	−16.6	262	−24.4	477	−15.0	299	−21.2
List 3	523	−15.8	350	−22.0	519	−15.2	389	−20.6
List 4	558	−16.7	343	−25.2	595	−15.1	354	−22.4
Overall	460	−16.7	262	−25.2	477	−15.2	299	−22.4
Ranges								
List 1	161	2.3	387	6.4	179	1.8	336	8.8
List 2	157	2.6	401	6.3	184	1.9	341	6.8
List 3	142	3.2	312	6.1	125	2.4	290	5.7
List 4	126	2.7	334	8.5	110	1.9	298	8.6
Overall	231	4.1	436	9.3	239	2.4	402	8.9

Note: The rms values are in dB, re: the maximum digitization range of the waveform editor.

data provided in Supplemental Tables S1–S4. The target words are numbered 1–50 in the figures that correspond to the NU-6, Randomization A numbering and word order that is followed in Supplemental Tables S1–S4. In the figures, the carrier phrases (open symbols) and target words (filled symbols) were parsed into the four respective lists. In each panel, the means for the data in the panel are depicted with the solid horizontal lines and ±1 SD are shown with the dashed lines. In both figures, there are a several relations to note. First, almost all of the carrier phrases have higher rms values than the rms values of the accompanying target words. There were four exceptions, all with the VA speaker and all with large amplitude, sustained vowels (List 1, #34, *moon*; List 4, #17, List 4, *mob*; List 4, #33, *make*; and List 4, #42, *near*). As exemplified in the waveform examples in Figures 2–5, the majority of target words have little sustained vowel energy and often short consonants both of which diminish the overall rms values. Second, overall the amplitude variability of the target words was about double the amplitude variability of the carrier phrase for the Auditec male speaker and about triple the variability of the carrier phrase for the VA female speaker. Third, the ranges of the carrier phrase amplitudes by list (Table 1) were 2–3 dB for both speakers, whereas the ranges of the target word amplitudes were mostly 6–9 dB, which approximate earlier reports of a 6-dB range for PB-50 words (Green et al, 1959) and an 8-dB range for Swedish PB words (Sjögren, 1973), both measured with a vu meter. Likewise, as recently pointed out by Killion (personal communication, 2014), similar measures on the Tillman version of NU-6 revealed that the carrier phrases were about 1 dB lower than the calibration tone with the amplitudes of the target words in a 1–4 dB range below the calibration tone. Collectively, the data from these studies demonstrate that the relation between the levels of the carrier phrases and target words is dependent, just as word-recognition performance is, on the particular recording (speaker) of the materials. This increased variability of the word amplitudes

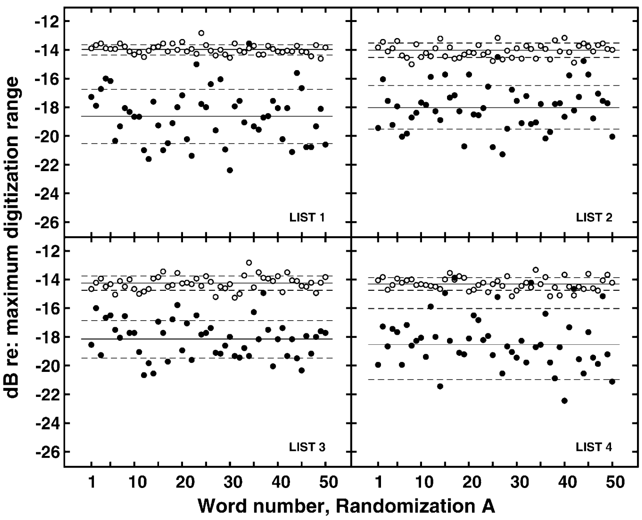

Figure 7. The rms values for the 50 carrier phrase (open symbols) and target word (filled symbols) sets are shown for the four lists of NU-6 recorded by the VA female speaker. The solid horizontal lines represent the mean values for each list and the dashed horizontal lines define ±1 standard deviation. The numeric data are listed in Supplemental Tables S1–S4.

compared to the variability of the carrier phrase amplitudes was expected as, in accordance with the 2010 American National Standards Institute standard,[2] the carrier phrases are recorded to the same vu level with the target word delivered in a natural manner following the carrier phrase without respect to the vu level.

Finally, because the amplitudes of the target words varied 6–9 dB, it was of interest to examine the relation between the rms levels of the target words and the recognition performances obtained on those words. The recognition data came from two sources, both of which were transformed and compiled by Wilson and McArdle (2015). The item analyses of the NU-6 materials spoken by the VA female speaker were obtained from 953 patients with sensorineural hearing loss (mean age = 69.9 yr) evaluated at the Bay Pines VA Healthcare System. Each listener was assigned to one of the four NU-6 lists resulting in 187–302 listeners/list. These recognition data for the 200 NU-6 words, which were obtained from Supplemental Table S11 in the Wilson and McArdle (2015) study, are presented in Figure 9 as bivariate plots with the percent correct recognition on the ordinate and the rms of the target words (in dB re: the maximum digitization range) on the abscissa. The large-filled symbol represents the mean data and the dashed line is a linear regression used to describe the data. The data are best characterized as having a random or "shotgun" pattern that is confirmed by the essentially flat slope of the regression ($m = -0.56\%$/dB; $r = -0.079$). The item analysis data for the Auditec male speaker version of NU-6 were reported by Hurley and Sells (2003) and were based on 222–225 listeners/list. The sample consisted of 92 ears with normal hearing for pure tones and 891 ears with sensorineural hearing loss (mean age = 52 yr). The Hurley and Sells recognition data for the 200 NU-6 words, which were obtained from Supplemental Table S7 in the Wilson and McArdle (2015) study, were compared with the rms levels of the target words and are presented as a bivariate plot in Figure 10. Again, the slope of the linear regression used to describe the data are essentially flat

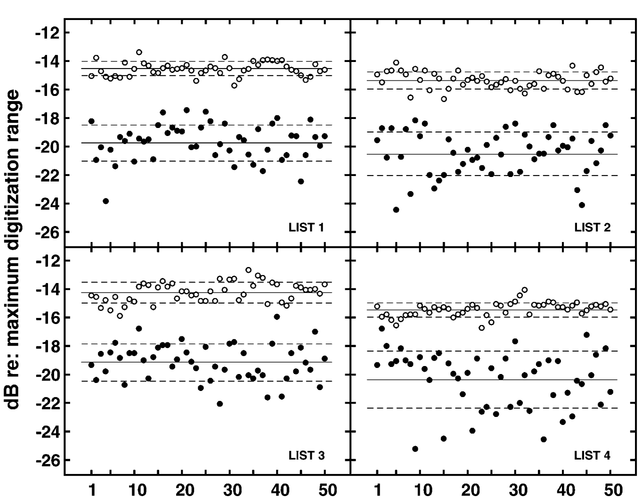

Figure 8. The rms values for the 50 carrier phrase (open symbols) and target word (filled symbols) sets are shown for the four lists of NU-6 recorded by the Auditec male speaker. The solid horizontal lines represent the mean values for each list and the dashed horizontal lines define ±1 standard deviation. The numeric data are listed in Supplemental Tables S1–S4.

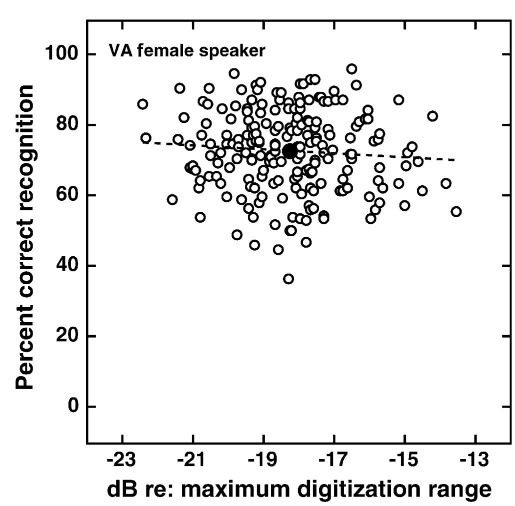

Figure 9. Bivariate plot of the percent correct recognition (ordinate) plotted as a function of the rms level of the 200 target words (abscissa). The data were obtained at the Bay Pines VA Healthcare System from 187 to 302 listeners/list with the NU-6 materials spoken by the VA female speaker (Wilson and McArdle, 2015). The mean data are represented by the large, filled circle, and the dashed line is the linear regression used to describe the data.

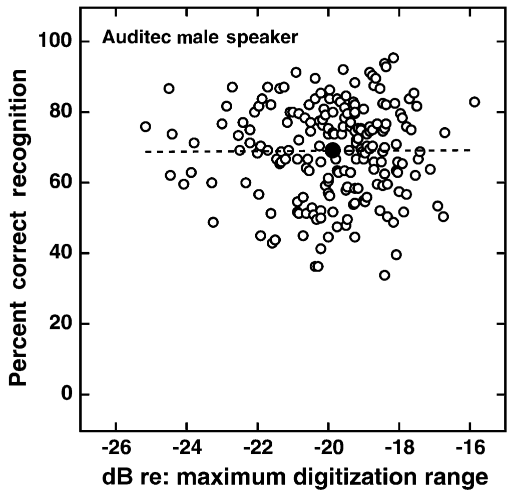

Figure 10. Bivariate plot of the percent correct recognition (ordinate) plotted as a function of the rms level of the 200 target words (abscissa). The data were obtained from 222–225 listeners/list with the NU-6 materials spoken by the Auditec male speaker (Hurley and Sells, 2003). The mean data are represented by the large, filled circle, and the dashed line is the linear regression used to describe the data.

($m = 0.03\%$/dB; $r = 0.004$), indicating a random relation between the two variables. Within the context of these two comparisons, the relative rms levels of the target words for both versions of NU-6 are not predictors of the recognition performances on those words. This random relation between the relative rms level and recognition of the words is not to be confused with the typical overall presentation levels of the word that can produce substantial differences in recognition performances among words presented in quiet or in noise.

SUMMARY

The rms levels of the carrier phrases commonly used with word-recognition materials closely approximate the rms levels of calibration tones when both are set to the same vu level. This relation supports the contention that the 4.8 dB relation between the rms and vu levels observed with running speech and sentence materials by Killion (2009) is not observed with the carrier phrase and target word paradigm commonly used clinically to measure word-recognition performance. The carrier phrases used with word-recognition testing have modest amplitude modulation characteristics compared to the amplitude modulation characteristics of the two types of materials evaluated by Killion. In this study, the rms levels of the target words typically were 6–9 dB lower than the rms levels of the companion carrier phrases. In addition, the amplitude variability of the target words was two to three times the amplitude variability of the carrier phrases. The mean durations of the carrier phrases were the same for the two versions of NU-6 (593 msec) with the target words spoken by the VA female speaker 38 msec longer than the target words spoken by the Auditec male speaker. Finally, the relation between the relative rms level of the target words and recognition performance on those words by listeners with sensorineural hearing loss for pure tones was random.

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Supplemental Table S1

Table SM1. The temporal (msec) and amplitude (rms) descriptive data for the carrier phrase and target words that were obtained for the Auditec and VA recordings of NU-6, List 1, Randomization A. The rms values are in dB, re: the maximum digitization range of the waveform editor.

		Auditec Recordings				VA Recordings			
		Carrier Phrase		Target Word		Carrier Phrase		Target Word	
		msec	rms (dB)	msec	rms (dB)	msec	rms (dB)	msec	rms (dB)
1	LAUD	460	-15.01	562	-18.18	716	-13.84	548	-17.25
2	BOAT	551	-13.71	616	-20.92	664	-13.62	433	-17.83
3	POOL	558	-14.69	546	-20.02	634	-13.50	541	-16.70
4	NAG	584	-15.07	581	-23.81	712	-13.83	615	-15.97
5	LIMB	499	-15.17	513	-20.17	647	-13.90	590	-16.10
6	SHOUT	512	-14.99	589	-21.36	600	-13.89	585	-20.26
7	SUB	532	-15.11	567	-19.28	602	-13.51	572	-19.29
8	VINE	494	-14.08	666	-19.56	600	-13.71	578	-18.02
9	DIME	523	-15.08	554	-19.09	590	-14.05	526	-18.28
10	GOOSE	511	-14.53	467	-21.03	582	-14.28	511	-18.63
11	WHIP	509	-13.36	523	-19.38	674	-14.13	482	-18.63
12	TOUGH	516	-14.14	435	-19.62	573	-14.44	469	-20.96
13	PUFF	523	-14.31	382	-19.47	594	-14.03	422	-21.56
14	KEEN	514	-14.74	562	-20.86	547	-13.79	542	-17.56
15	DEATH	523	-14.80	411	-18.44	579	-13.74	453	-19.22
16	SELL	508	-14.48	618	-17.56	600	-13.48	641	-20.97
17	TAKE	573	-14.27	337	-19.01	563	-14.06	462	-20.46
18	FALL	514	-14.57	613	-18.64	585	-13.49	617	-19.09
19	RAISE	521	-14.49	643	-18.86	604	-13.95	695	-17.96
20	THIRD	538	-14.47	550	-18.92	602	-13.42	529	-17.13
21	GAP	532	-14.24	311	-17.41	583	-14.04	498	-20.17
22	FAT	559	-14.64	440	-19.99	585	-13.90	601	-21.35
23	MET	563	-15.36	411	-19.95	600	-14.23	497	-14.97
24	JAR	581	-14.78	564	-18.64	586	-12.78	547	-17.73
25	DOOR	585	-14.63	448	-17.50	581	-13.63	473	-17.93
26	LOVE	591	-14.34	601	-18.16	579	-13.98	484	-16.33
27	SURE	591	-14.47	589	-20.55	578	-14.32	597	-19.58
28	KNOCK	595	-14.79	415	-19.78	562	-13.93	613	-16.00
29	CHOICE	512	-13.68	562	-18.37	564	-14.30	625	-20.89
30	HASH	573	-14.47	512	-20.26	537	-14.52	647	-22.32
31	LOT	566	-15.67	569	-21.38	574	-13.53	540	-17.87
32	RAID	592	-15.25	582	-19.27	583	-13.98	593	-17.52

Table SM1, continued

33	HURL	603	-14.63	570	-19.52	583	-14.13	573	-18.98
34	MOON	595	-14.49	570	-20.50	578	-13.82	549	-13.52
35	PAGE	555	-13.96	561	-21.22	558	-13.67	600	-19.29
36	YES	541	-14.25	468	-18.75	588	-14.27	625	-19.48
37	REACH	591	-13.91	507	-21.65	587	-14.28	588	-18.65
38	KING	539	-13.84	471	-20.17	587	-13.68	553	-18.54
39	HOME	561	-13.90	483	-18.37	563	-13.90	554	-17.51
40	RAG	537	-13.94	563	-17.95	580	-14.08	593	-18.00
41	WHICH	565	-13.90	562	-20.90	688	-14.11	690	-20.18
42	WEEK	550	-14.37	355	-20.59	578	-14.01	503	-18.00
43	SIZE	559	-14.55	698	-19.16	619	-14.04	701	-21.05
44	MODE	568	-14.66	527	-19.22	594	-13.65	584	-15.58
45	BEAN	594	-14.94	511	-22.41	581	-14.08	534	-16.60
46	TIP	552	-15.28	322	-20.57	593	-14.12	366	-20.74
47	CHALK	562	-15.09	369	-18.04	612	-14.42	570	-20.72
48	JAIL	602	-14.20	538	-19.29	622	-13.60	537	-19.29
49	BURN	621	-14.69	528	-19.90	615	-14.58	544	-18.05
50	KITE	580	-14.57	329	-19.26	600	-13.80	473	-20.56
	Mean	552	-14.53	513	-19.66	598	-13.92	553	-18.59
	SD	35	0.49	93	1.30	38	0.33	70	1.88
	Max	621	-13.36	698	-17.41	716	-12.78	701	-13.52
	Min	460	-15.67	311	-23.81	537	-14.58	366	-22.32
	Range	161	2.31	387	6.40	179	1.80	335	8.80
	Calibration tone		-15.3				-14.0		

Supplemental Table S2

Table SM2. The temporal (msec) and amplitude (rms) descriptive data for the carrier phrase and target words that were obtained for the Auditec and VA recordings of NU-6 List 2, Randomization A. The rms values are in dB, re: the maximum digitization range of the waveform editor.

		Auditec Recordings				VA Recordings			
		Carrier Phrase		Target Word		Carrier Phrase		Target Word	
		msec	rms (dB)	msec	rms (dB)	msec	rms (dB)	msec	rms (dB)
1	PICK	538	-14.91	263	-19.51	584	-13.78	399	-19.38
2	ROOM	554	-15.44	434	-18.69	569	-13.42	520	-15.99
3	NICE	553	-14.65	628	-20.70	586	-14.08	598	-17.48
4	SAID	574	-14.60	522	-18.65	559	-13.85	575	-19.16
5	FAIL	543	-14.07	547	-24.42	563	-13.31	572	-17.92
6	SOUTH	575	-14.64	623	-20.68	527	-14.33	536	-19.99
7	WHITE	551	-14.87	370	-18.72	656	-14.50	511	-19.79
8	KEEP	534	-16.48	267	-23.27	646	-14.97	465	-18.69
9	DEAD	581	-14.53	374	-18.09	571	-13.58	462	-18.31
10	LOAF	550	-15.28	470	-19.25	576	-14.47	516	-17.63
11	DAB	594	-14.61	483	-18.35	561	-14.17	465	-17.76
12	NUMB	613	-15.98	527	-21.95	550	-14.38	528	-15.83
13	JUICE	630	-14.83	530	-22.90	583	-13.84	536	-18.25
14	CHIEF	596	-15.19	530	-22.35	551	-13.19	568	-18.81
15	MERGE	691	-16.64	634	-21.93	565	-14.39	590	-15.67
16	WAG	616	-15.87	559	-19.45	571	-13.79	592	-17.26
17	RAIN	597	-15.17	547	-20.39	550	-14.58	603	-17.14
18	WITCH	613	-14.62	572	-21.71	564	-14.50	543	-18.21
19	SOAP	590	-15.60	663	-21.19	554	-14.28	539	-20.68
20	YOUNG	623	-15.28	584	-20.15	538	-14.10	534	-15.67
21	TON	585	-15.12	467	-20.88	502	-14.18	503	-18.43
22	KEG	563	-15.36	467	-20.72	519	-13.61	489	-18.48
23	CALM	588	-15.01	578	-21.45	489	-14.26	530	-18.02
24	TOOL	671	-15.42	526	-19.84	558	-14.12	481	-16.53
25	PIKE	588	-15.78	333	-21.92	511	-14.73	458	-20.75
26	MILL	608	-15.63	500	-19.31	562	-13.10	440	-14.47
27	HUSH	604	-15.45	463	-20.50	514	-14.61	520	-21.23
28	SHACK	575	-15.25	425	-18.57	477	-13.98	576	-19.44
29	READ	635	-15.99	584	-21.87	527	-14.50	516	-16.70
30	ROT	604	-15.35	452	-18.33	540	-13.81	515	-17.52
31	HATE	603	-15.90	306	-21.73	559	-14.55	453	-19.06
32	LIVE	575	-16.20	509	-19.11	606	-13.69	457	-17.15

Table SM2, continued

33	BOOK	613	-15.69	262	-19.97	573	-13.88	346	-19.14
34	VOICE	632	-15.58	598	-20.85	551	-14.54	547	-19.01
35	GAZE	625	-14.66	547	-20.44	501	-13.66	529	-17.75
36	PAD	655	-15.89	543	-20.47	574	-13.92	501	-20.14
37	THOUGHT	619	-14.97	445	-19.26	539	-14.64	414	-19.69
38	BOUGHT	649	-14.83	370	-18.44	575	-13.26	521	-17.71
39	TURN	641	-15.05	535	-20.21	582	-14.08	539	-17.69
40	CHAIR	611	-15.32	556	-19.88	596	-13.11	516	-18.64
41	LORE	605	-15.96	545	-19.99	539	-14.10	458	-15.71
42	BITE	615	-14.28	350	-19.37	550	-14.85	394	-18.17
43	HAZE	613	-16.12	610	-23.01	525	-13.66	579	-17.24
44	MATCH	606	-16.13	568	-24.08	553	-13.52	623	-14.75
45	LEARN	619	-14.94	601	-21.65	546	-13.71	555	-15.69
46	SHAWL	603	-15.58	621	-19.57	632	-14.06	640	-18.75
47	DEEP	626	-14.75	326	-21.11	585	-13.63	299	-17.00
48	GIN	622	-14.41	480	-20.22	575	-13.49	480	-17.52
49	GOAL	577	-15.38	511	-18.45	661	-13.92	556	-17.65
50	FAR	592	-15.16	558	-19.17	525	-13.93	550	-20.01
	Mean	601	-15.29	495	-20.45	559	-14.01	513	-17.99
	SD	33	0.58	104	1.55	38	0.47	68	1.55
	Max	691	-14.07	663	-18.09	661	-13.10	640	-14.47
	Min	534	-16.64	262	-24.42	477	-14.97	299	-21.23
	Range	157	2.57	401	6.33	184	1.87	341	6.76
	Calibration tone		-15.3				-14.0		

Supplemental Table S3

Table SM3. The temporal (msec) and amplitude (rms) descriptive data for the carrier phrase and target words that were obtained for the Auditec and VA recordings of NU-6 List 3, Randomization A. The rms values are in dB, re: the maximum digitization range of the waveform editor.

		Auditec Recordings				VA Recordings			
		Carrier Phrase		Target Word		Carrier Phrase		Target Word	
		msec	rms (dB)	msec	rms (dB)	msec	rms (dB)	msec	rms (dB)
1	BASE	584	-14.39	454	-19.26	532	-14.63	467	-18.51
2	MESS	537	-14.49	500	-20.35	537	-14.15	571	-15.93
3	CAUSE	556	-15.27	604	-18.50	570	-13.92	539	-19.20
4	MOP	523	-14.71	435	-19.71	634	-14.44	548	-16.59
5	GOOD	548	-15.45	389	-18.41	570	-14.26	417	-16.45
6	LUCK	524	-14.52	419	-17.72	581	-14.99	458	-17.45
7	WALK	560	-15.82	490	-18.78	567	-14.08	568	-18.00
8	YOUTH	542	-15.22	515	-20.65	580	-14.45	508	-16.52
9	PAIN	603	-14.66	548	-18.45	569	-13.93	538	-17.65
10	DATE	619	-14.81	358	-18.44	570	-14.60	389	-17.69
11	PEARL	619	-13.76	482	-16.74	570	-14.95	503	-19.03
12	SEARCH	608	-13.56	584	-18.96	577	-14.78	637	-20.59
13	DITCH	631	-13.68	427	-20.21	589	-14.62	487	-19.77
14	TALK	603	-15.22	403	-18.71	575	-13.92	457	-20.50
15	RING	574	-13.83	504	-18.06	592	-13.79	484	-16.91
16	GERM	608	-13.39	528	-17.88	567	-13.37	535	-17.67
17	LIFE	634	-13.78	532	-17.92	559	-14.44	438	-19.69
18	TEAM	626	-13.54	524	-19.37	594	-14.33	473	-16.70
19	LID	587	-14.63	470	-18.92	602	-13.51	485	-15.73
20	POLE	577	-14.14	491	-17.45	551	-14.21	481	-18.89
21	RODE	644	-14.14	600	-18.40	576	-14.16	546	-16.98
22	SHALL	608	-14.41	647	-19.06	586	-14.26	620	-19.58
23	LATE	607	-14.31	382	-19.50	591	-13.91	456	-16.46
24	CHEEK	638	-14.78	490	-20.90	607	-14.41	440	-17.76
25	BEG	631	-14.79	434	-18.02	584	-13.72	423	-17.65
26	GUN	630	-14.09	446	-20.38	519	-14.14	456	-17.33
27	JUG	618	-14.76	479	-19.41	600	-15.17	489	-19.06
28	SHEEP	665	-13.20	463	-22.02	558	-14.43	529	-19.11
29	FIVE	625	-14.02	635	-19.60	538	-14.54	479	-18.57
30	RUSH	657	-13.26	543	-17.80	540	-14.26	603	-17.93
31	RAT	642	-13.24	477	-17.67	564	-15.21	508	-19.30
32	VOID	587	-14.70	523	-20.09	534	-14.95	557	-19.39
33	WIRE	623	-14.31	575	-18.45	586	-13.69	530	-18.74

Table SM3, continued

34	HALF	654	-12.62	581	-20.01	574	-12.78	481	-19.27
35	NOTE	630	-13.73	600	-20.22	564	-14.50	502	-16.24
36	WHEN	646	-12.98	520	-19.66	576	-13.45	565	-18.09
37	NAME	622	-13.19	578	-19.98	608	-13.81	557	-14.88
38	THIN	613	-15.03	443	-21.58	562	-13.92	439	-17.45
39	TELL	621	-13.48	521	-17.79	580	-14.05	466	-20.01
40	BAR	642	-13.64	457	-15.90	622	-13.75	445	-18.13
41	MOUSE	616	-14.92	604	-21.49	573	-14.86	679	-17.34
42	HIRE	609	-15.09	500	-20.24	587	-13.43	507	-19.29
43	CAB	632	-14.63	525	-18.45	610	-13.99	523	-18.09
44	HIT	613	-13.74	350	-19.74	588	-14.05	455	-19.44
45	CHAT	611	-13.81	372	-18.08	582	-14.39	532	-20.30
46	PHONE	610	-14.03	560	-19.11	553	-14.46	554	-17.89
47	SOUP	631	-14.03	397	-19.59	630	-14.15	571	-19.09
48	DODGE	605	-13.94	535	-16.94	616	-14.88	561	-17.93
49	SEIZE	593	-14.30	662	-20.85	622	-14.19	653	-17.54
50	COOL	594	-13.59	548	-18.86	644	-13.76	457	-17.69
	Mean	608	-14.19	502	-19.09	579	-14.21	511	-18.12
	SD	34	0.70	77	1.28	27	0.50	63	1.31
	Max	665	-12.62	662	-15.90	644	-12.78	679	-14.88
	Min	523	-15.82	350	-22.02	519	-15.21	389	-20.59
	Range	142	3.20	312	6.12	125	2.43	290	5.71
	Calibration tone		-15.3				-14.0		

Supplemental Table S4

Table SM4. The temporal (msec) and amplitude (rms) descriptive data for the carrier phrase and target words that were obtained for the Auditec and VA recordings of NU-6 List 4, Randomization A. The rms values are in dB, re: the maximum digitization range of the waveform editor.

		Auditec Recordings				VA Recordings			
		Carrier Phrase		Target Word		Carrier Phrase		Target Word	
		msec	rms (dB)	msec	rms (dB)	msec	rms (dB)	msec	rms (dB)
1	PASS	563	-15.16	584	-19.28	611	-13.99	626	-19.90
2	DOLL	597	-15.88	462	-16.73	645	-13.80	494	-17.24
3	BACK	567	-15.70	356	-17.94	621	-14.67	540	-18.60
4	RED	610	-16.13	465	-19.25	655	-14.31	503	-17.37
5	WASH	598	-16.51	527	-19.01	622	-13.88	620	-17.61
6	SOUR	607	-16.04	590	-18.10	624	-14.15	627	-19.92
7	BONE	636	-15.77	473	-18.94	650	-14.00	506	-17.11
8	GET	624	-15.73	343	-19.23	650	-13.95	408	-18.57
9	WHEAT	626	-15.75	434	-25.19	669	-14.35	513	-18.22
10	THUMB	592	-15.10	493	-18.73	621	-14.26	460	-17.99
11	SALE	619	-15.33	615	-19.54	610	-14.32	582	-19.35
12	YEARN	684	-15.60	677	-20.31	639	-14.42	602	-15.82
13	WIFE	664	-15.21	522	-18.76	630	-14.45	497	-17.94
14	SUCH	626	-15.37	561	-18.44	620	-14.64	603	-21.38
15	NEAT	619	-15.25	474	-24.46	705	-13.97	479	-14.92
16	PEG	659	-15.32	451	-19.17	635	-13.49	475	-18.25
17	MOB	645	-15.95	534	-19.87	613	-13.93	581	-13.81
18	GAS	631	-15.74	548	-20.20	609	-13.72	565	-19.04
19	CHECK	639	-15.59	482	-21.36	624	-13.81	493	-19.19
20	JOIN	648	-15.34	606	-19.82	623	-14.79	576	-18.04
21	LEASE	623	-15.08	567	-23.90	632	-14.65	571	-16.45
22	LONG	662	-15.28	652	-18.83	595	-14.34	618	-16.79
23	CHAIN	624	-16.67	591	-22.57	615	-14.17	568	-18.16
24	KILL	631	-15.80	421	-22.21	631	-14.82	476	-17.91
25	HOLE	668	-16.30	546	-19.48	635	-14.30	510	-19.23
26	LEAN	673	-15.00	599	-22.73	627	-14.07	574	-15.15
27	TAPE	648	-15.14	430	-20.11	667	-14.40	442	-20.52
28	TIRE	654	-15.62	483	-18.86	618	-13.71	514	-18.64
29	DIP	675	-14.99	500	-22.20	664	-15.09	369	-18.99
30	ROSE	649	-14.83	644	-17.60	646	-14.70	652	-19.41
31	CAME	616	-14.39	532	-21.97	635	-14.42	571	-18.21
32	FIT	592	-14.02	400	-19.99	617	-14.17	354	-19.73
33	MAKE	626	-15.74	443	-22.51	643	-14.53	534	-14.16

Table SM4, continued

34	VOTE	606	-15.04	448	-19.75	666	-13.27	557	-18.69
35	JUDGE	609	-15.09	562	-19.20	649	-14.27	525	-18.48
36	FOOD	572	-15.08	606	-24.52	658	-13.76	622	-16.35
37	RIPE	577	-14.81	556	-18.96	596	-15.12	511	-19.70
38	HAVE	587	-14.91	615	-21.37	609	-14.49	589	-20.82
39	ROUGH	558	-15.24	467	-19.02	657	-15.05	477	-18.65
40	KICK	590	-15.20	409	-23.30	625	-13.61	430	-22.40
41	LOSE	570	-15.41	575	-21.25	680	-14.43	612	-17.29
42	NEAR	589	-15.09	527	-22.89	604	-15.04	550	-14.59
43	PERCH	578	-14.89	498	-20.37	656	-14.45	597	-19.54
44	SHIRT	561	-15.66	526	-20.63	671	-14.61	553	-20.48
45	BATH	568	-15.47	506	-17.15	629	-13.56	368	-17.62
46	TIME	559	-15.15	564	-20.00	651	-14.57	600	-19.39
47	HALL	562	-15.07	596	-18.57	663	-14.72	650	-19.84
48	MOOD	564	-15.16	619	-22.08	662	-14.01	587	-15.12
49	DOG	579	-15.03	547	-18.13	662	-13.61	521	-19.16
50	SHOULD	584	-15.38	555	-21.15	698	-14.19	544	-21.05
	Mean	612	-15.38	524	-20.31	639	-14.26	536	-18.26
	SD	36	0.49	76	2.00	25	0.44	73	1.89
	Max	684	-14.02	677	-16.73	705	-13.27	652	-13.81
	Min	558	-16.67	343	-25.19	595	-15.12	354	-22.40
	Range	126	2.65	334	8.46	110	1.85	298	8.59
	Calibration tone		-15.3				-14.0		