An Orthographic Way of Writing English Prosody

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An alphabetic process for cueing readers to speak the three dimensions of sound in speech has been constructed: fundamental frequency, duration, and intensity. A scanning model based on differences in the apparent levels of the three dimensions is presented. Considerations of the information in an alphabetic approach are discussed.

The two objectives of this paper are: to write prosodic levels with graphic symbols applicable to many spoken languages, and to formulate conversions of prosodic into stress levels. Discussions of the terms "acoustic level," "stress level," and "prosodic level" are required for clarification.

Prosody is a vague term. It is associated with systems of versification that may depend on "length" or duration of syllables (Greek),[1] or orderings of weak and strong stressed syllables (English); on rhyme and quasi-rhyme schemes; on stanza arrangements; on relations of syllables to musical notation, etc. All prosodic systems possess two characteristics: they are *written* rhythms of speech and their patterns are *systematic instructions by writers* to readers to speak in specified ways. It is essential to realize that "prosodic levels" must be written. Although every person does hear different levels of loudness or pitch in face-to-face conversation, a continuous symbol system of live speech cannot be fixed or analyzed in detail, or structured or programmed without memory storage of written or other recordings of language. Consequently, prosodic systems connect written and spoken language by graphic cues that identify and program selected units of speech rhythm. We will operate with graphic cues by modifying letters of the alphabet (Fig. 1A).

A written prosodic level is a graphic symbol that identifies a

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perceptible acoustic level and instructs the reader to speak that level. Here, the graphic symbols are elevation, darkness, and length of letter. Since these graphic dimensions are built into the structure of letters, they produce orthographic symbols (Figs. 1A, 1B).

A level is ambiguous without a reference standard. The constant reference for perceiving variations of written prosodic levels is, simply, the normal appearance of letters. It is from this norm that readers judge whether vowels are elevated or lowered; whether all letters are squeezed or stretched out; or noticeably dark or faint. "Normal" appearance is the uniformity of letters consistent with a single style of typography or chirography.

"Acoustic levels" of speech are standard calibrated and instrumentally measured correlates of speech: fundamental frequency in Hz, sound pressure level in dynes, time duration and silences in centiseconds. These energy plateaus and time dimensions constitute the most universal physical features and coordinates of stress and prosodic levels. The prosodic correlates to acoustic levels are: perceived pitch for fundamental frequency, duration for time, perceived effort and force of speech for amplitude level and pauses for silences. "Speech power" may be used for convenience, in its loose sense as a perceptual term for "effort and force"; this only for the purpose of instruction to subjects.

A spoken prosodic level is vocalization of a perceived acoustic level in obedience to written instructions. The form of the instruction may be the ◡/ markings of the English department's "feet" which are simply stressed versus unstressed syllables. Other instructions may be diacritical markings such as Trager and Smith's 1, 2, 3, 4 markings for "pitch" levels, and /, ^, \, ◡ for four levels of stress.[2] During the eighteenth and nineteenth centuries prosodic instructions to speak "loudness" levels, pitch levels, time, and pause durations were written with musical notations as in the systems of Joshua Steele and Dr. Benjamin Rush.[3] Even though prosodic levels are "naturally" present in face-to-face speech, the vocal performance of prosodic systems as in singing or playing a musical instrument requires training, practice, and no audio-vocal disabilities.

Stress levels are impressions of loudness relative to the average

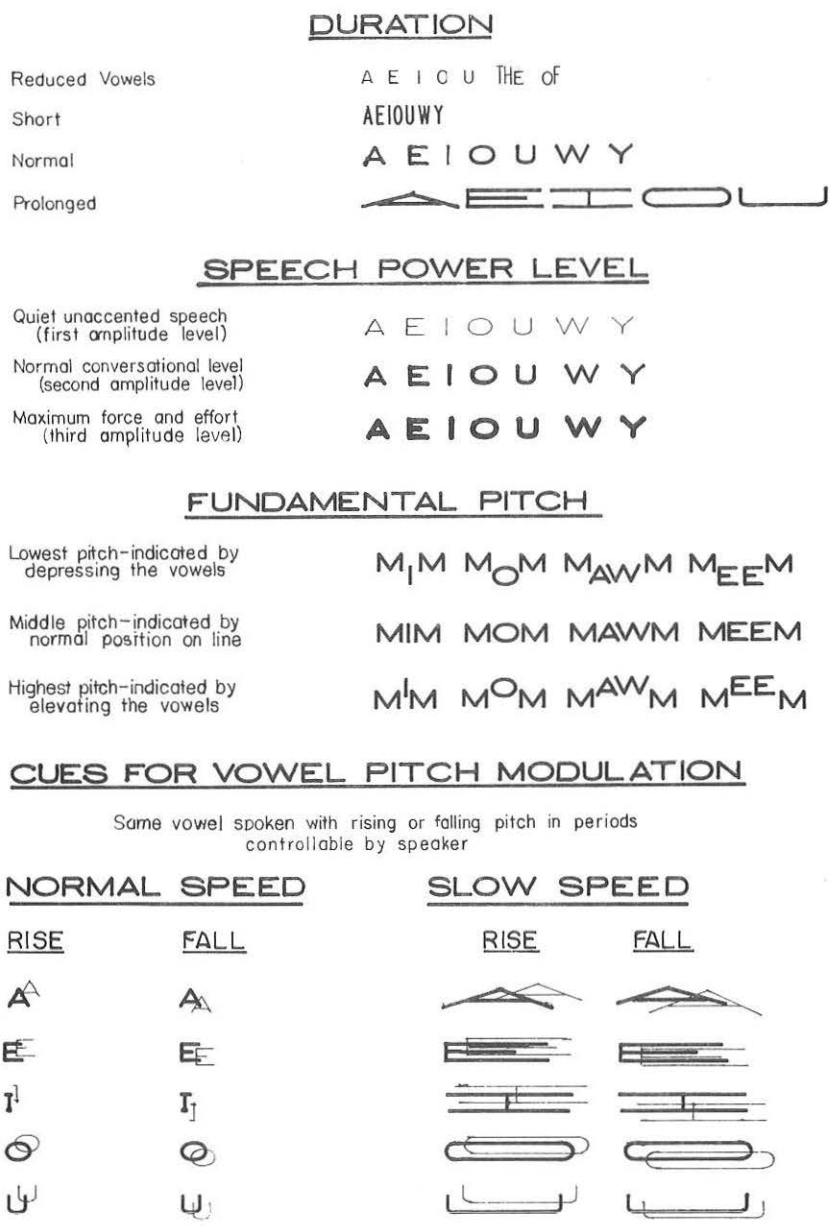


Figure 1A.
Prosodynic code for writing the English alphabet with structured letters that cue the reader to speak the acoustic levels of prosody.

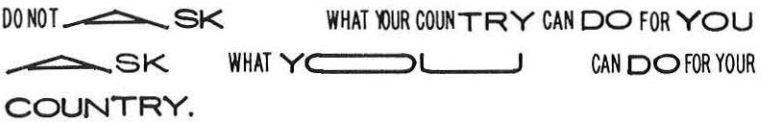
ENGLISH SPELLING

DO NOT ASK WHAT YOUR COUNTRY CAN DO FOR YOU, ASK WHAT YOU CAN DO FOR YOUR COUNTRY.

AMPLITUDE

DO NOT ASK WHAT YOUR COUNTRY CAN DO FOR YOU ASK WHAT YOU CAN DO FOR YOUR COUNTRY.

TIME



PITCH

AMPLITUDE+TIME+PITCH+PAUSES

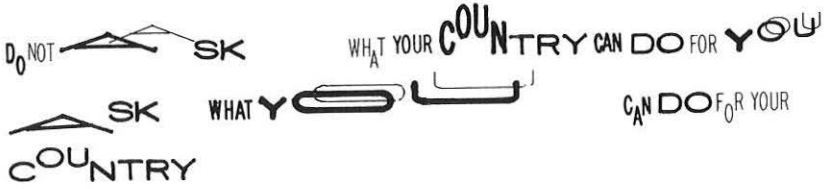


Figure 1B.
Prosodynic cues written separately and combined.

Figure 1C.
Prosodynic writing of phonetic English. Notice adjustability of the independent dimensions in the prosodynic code.

loudness of an individual talker. They are auditory perceptions of undifferentiated vocal energy. It is assumed that native speakers of English who listen, repeatedly, to a single English sentence can identify and specify with markings, three to four levels of stress. The acoustic correlates of stress or loudness include all the acoustic correlates (fundamental frequency, amplitude, and time) of prosodic levels. It is not surprising that listeners will judge the relative loudness of synthesized speech according to the magnitude of the energy levels independent of which acoustic correlate was "traded" or substituted. In correspondence Pierre Delattre has stated, "It is true that amplitude and duration can affect our perception of intonation. (With speech synthesizers I can produce the impression of rises in pitch by over-emphasizing the duration as long as the

amplitude is not below normal)." It is the limited information potential of three to four stress levels per syllable in contrast to nine prosodic levels per syllable that indicates the richer speech pattern potential inherent in a prosodynic cue system. This increase of speech information creates problems involved with the capabilities of speakers, the peculiarities of English, the training of speakers, and other questions beyond the scope of this paper.

Perception of acoustic levels will increase both with redundancy and with reduced or context free language.[4] Context free English occurs in specialized languages of poetry, advertising, song lyrics, nonsense syllables, short phrases in speech research, short sequences in foreign language teaching, speech therapy, deaf pedagogy, and any isolated short sequence of language of four to five syllables. Over the last forty years instrumental measurements of context reduced language show that listeners can recognize at least three levels of fundamental frequency, three levels of amplitude, and three periods of duration.[5]

The perceived acoustic dimensions and levels of prosody must be recorded in a readable form to be available for use and understanding by speech and language specialists in many areas. If they are presented solely by spectrographic or other instrumental displays, both cost and convenience impose severe limitations. The kind of notation becomes important for teaching and creative uses. Diacritical notations—even when restricted to a few suprasegmentals such as juncture, intonation, and stress—have shown serious deficiencies.[6]

Integrating Prosodic Levels with the English Alphabet

Alphabetic cues which instruct readers to speak prosodic levels specified by the *length, height, and darkness* of letters seem to make several constributions. First, they graphically denote with the same symbol system (letters) all the acoustic dimensions of prosody carried by phonemes, syllables, words, phrases, contours, and sentence envelopes. Secondly, the graphic aspects of the script enable readers to scan stress patterns and visualize acoustic levels. This kind of writing is, literally, a display of transitions from perceived acoustic to stress levels; and the converse. Heights and slopes of levels are essential components of these displays as in spectrographs

of fundamental pitch or intonation.[7] A third asset of alphabetic cues is their capacity to show variations of intensity and duration of consonants, variations that modify stress.[8] Fourthly, the change in fundamental frequency of a vowel synchronized with intensity and duration variations can be written as "pitch modulation" cues (Fig. 1B). Fifth, a prosodic expression of the semantic intent of the writer can be written. Alphabetic cues which instruct readers to speak prosodic levels specified by the length, height, and darkness of letters are called "prosodynes" (Fig. 1C).[9]

In linguistics the "schwa" is now termed a reduced vowel. When we scan spectrographs, visually, a reduced phoneme appears as a trace. We shall use "reduced" and "trace" interchangeably. The trace warrants special consideration. There is a physical reason for attaching a value of 1 to the reduced vowel or syllable. The reduced vowel is essential in prosody because it operates as a cue for continuity or discontinuity of speech. Its faint and rapid glottal rumble puts sharp dips into the acoustic rhythm of English. Reduction obliterates distinctive features and minimizes the quality in levels of pitch and loudness close to the thresholds of perception (i.e., to no quality). Therefore the trace is allocated no perceived pitch or amplitude values. Yet a reduced vowel exists. It consumes noticeable time. Consequently, the reduced vowel or syllable has been designed to be singular (Figure 2). It is labeled "1" among the numbers given to prosodic levels. This cue is written $A \rightarrow o\ T_1\ P \rightarrow o$ to show pitch and amplitude approaching 0 in perceptive value. The information of the trace plus pitch modulation cues considerably increases the potential of prosodynic print.

Scanning with Prosodynic Levels

A prosodic number is the sum of numbers assigned to each perceived acoustic level of pitch, force, and duration. The largest prosodic number for a vowel equals the sum of the three numbers denoting the highest level of perceived pitch 3, the most powerful amplitude level 3, and the longest time extension 3. The sum is 9. This will be the most stressed vowel or syllable. The smallest sum of level numbers in a vowel will be 1 for the singular trace syllable or vowel. This is the least stressed syllable. The larger the prosodic number, the greater the amount of acoustic energy and stress value (Fig. 3).

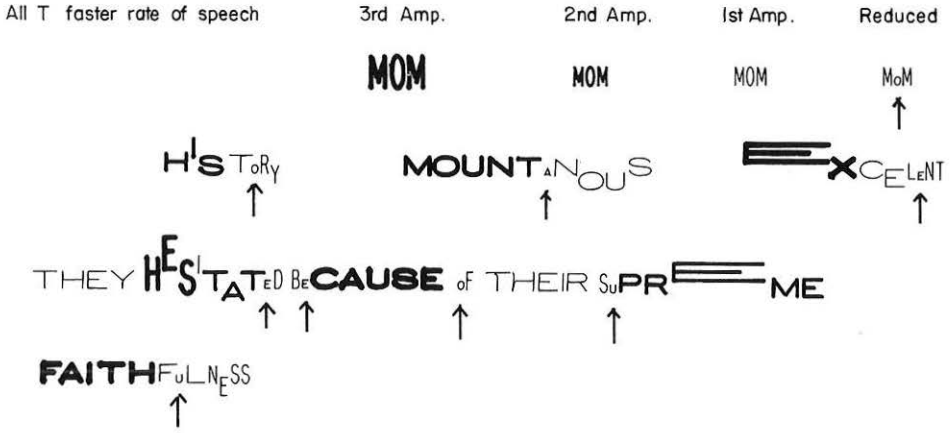


Figure 2.
The graphic cue for reduced vowels or syllables. Although this "schwa" cue is needed, arithmetically, to specify four stress levels and is a readable cue, speakers seldom articulate a reduced A—o, T_1 P—o vowel differently from an A_1 T_1 P_1. See note under Figure 5 for arithmetical operations that support a value of 1 for reduced vowels.

Figure 3.
Qualitative associations between numbers of stress levels and numbers of prosodic levels.

	Stress Level	Stress Quality	Prosodic Amp. T P Number	Prosodic Quality
A	1	Minimum Detectability	0 + 1 + 0 = 1	Reduced
CAN	1	Inconspicuous	1 + 1 + 1 = 3	Weak
TEST	2	Inconspicuous	1 + 2 + 1 = 4	Weak
BE	2	Between inconspicuousness and prominence	1 + 1 + 3 = 5	Between Weak and Rich
DANCE	3	Prominent	2 + 1 + 3 = 6	Rich
CON	3	Prominent	2 + 2 + 3 = 7	Rich
ONE	4	Most Conspicuous	3 + 2 + 3 = 8	Powerful
WILD	4	Most Conspicuous	3 + 3 + 3 = 9	Powerful
BALL	4	Most Conspicuous	3 + 3 + 3+ = 9+	Rich and Powerful

Stress levels here are synonomous with "loudness" levels. These levels are functions of objective and subjective components. The objective parameters are three measurable "acoustic levels"; the subjective factors are three prosodic levels each "a *perceived* acoustic level." Prosodynic levels are both written and spoken. They can be assessed as contributors to "stress" or loudness. It is understood that listeners may concentrate on stress at one time, and on the prosodic levels that produce stress or loudness at another. Targets of attention are involved with training. Although "stress" or "loudness" are produced by many non-acoustic influences, here, on a phonological basis stress is the impression of gross undifferentiated loudness carried by the longitudinal waves of sound. Figure 4 shows how many distributions of prosodic levels may produce the same stress level and why "trading" in prosodic levels occurs.[10] Writers of prosodynic print continuously operate with this kind of trading.

When we scan the speech rhythms of English with these numerical measures, we gain insight by understanding the problems of a writer intent on writing phrases and sentences with prosodynic script. Here is where judgments enter. The maximum number of gross stress levels amounts to 4. It is easier to first select a stress pattern of 4 levels than to first think of 46 prosodic levels. Once the stress pattern is structured, then prosodic levels fall into shape.

A simple arithmetic can convert prosodic into stress levels. We have represented the perceived pitch, amplitude, and time levels by the numbers 1, 2, 3, ranging from small to large. *Then, to determine the stress level of any particular vowel or syllable with respect to its . . neighbor take the difference between the sums of the numbers assigned for pitch, perceived amplitude, or time and divide by two.* Thus a difference of two prosodic numbers on two syllables will give one stress level difference, etc. Since the smallest prosodic number is 1 for the trace and the largest is 9, the highest stress level is $\frac{9\text{-}1}{2}$ or 4. In English, 4 has been accepted as a maximum stress level by many workers.[11] Divisions by two are supported by experiments. These show that whenever two prosodic levels of two neighboring syllables—such as pitch and duration, or pitch and perceived amplitude, or perceived amplitude and duration—increases in the same

PROSODIC FREEDOM OF THE WRITER

n = the sum of numbers assigned to levels of perceived pitch, amplitude and duration. These are prosodic numbers specified for a specific vowel or syllable by the writer.

Column totals = summations of *number of ways* of writing a prosodic number. Each of these permutations may be considered a "prosodic state."

(n=9)	(n=8)	(n=7)	(n=6)	(n=5)	(n=4)	(n=3)
A+P+T	A+P+T	A+P+T	A+P+T	A+P+T	A+P+T	A+P+T
3+3+3	2+3+3	1+3+3	2+2+2	1+3+1	2+1+1	1+1+1
1	3+2+3	3+1+3	3+2+1	3+1+1	1+1+2	3
	3+3+2	3+3+1	2+3+1	1+1+3	1+2+1	
	3	3+2+2	3+1+2	2+2+1	3	
		2+3+2	1+3+2	2+1+2		
		2+2+3	1+2+3	1+2+2		
		6	2+1+3	6		
			7			

1+3+6+7+6+3+1=27 = number of choices for the writer of non-modulated syllables

(n=9)	(n=8)	(n=7)	(n=6)	(n=5)	(n=4)	(n=3)
A+PP+T	A+PP+T	A+PP+T	A+PP+T	A+PP+T	A+PP+T	A+PP+T
3+3 +3	3+3 +2	3+2 +2	3+1 +2	2+1 +2	1+1 +2	Nothing because fast duration is impossible for pitch modulation
1	3+2 +3	2+3 +2	2+2 +2	1+2 +2	1	
	2+3 +3	2+2 +3	1+3 +2	1+1 +3		
	3	1+3 +3	2+1 +3	3		
		3+1 +3	1+2 +3			
		5	5			

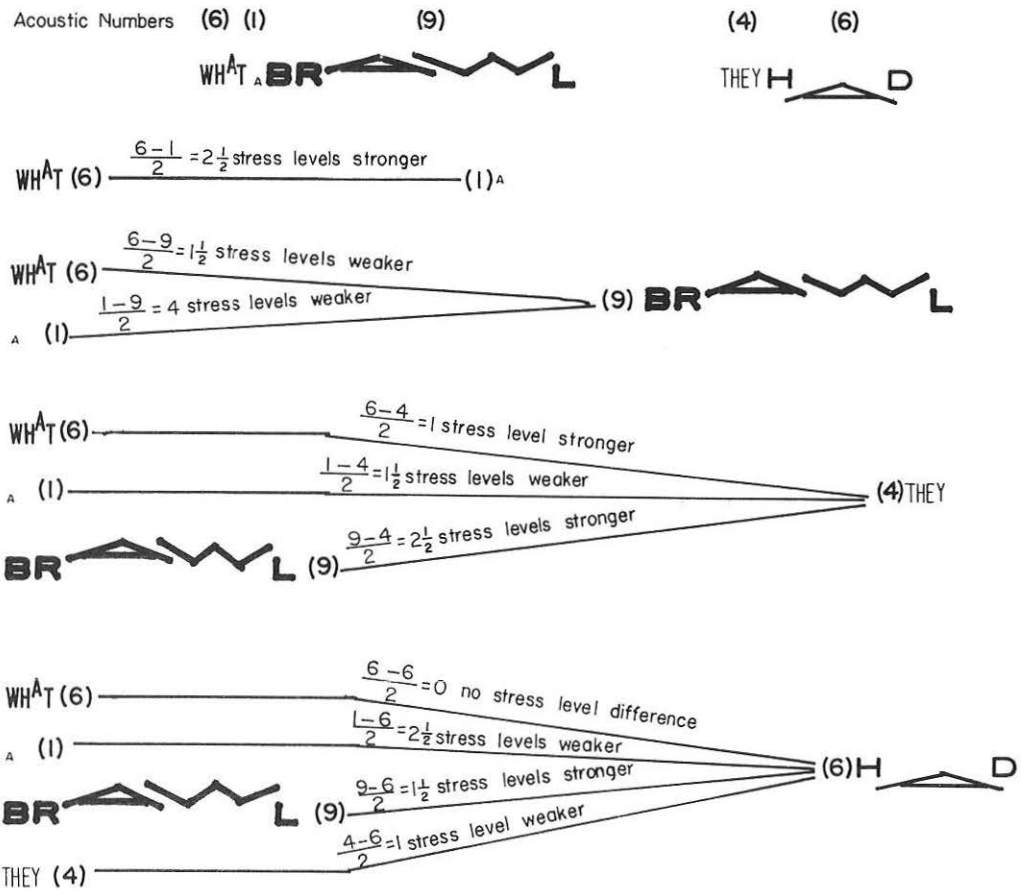
1+3+5+5+3+1=18 = number of choices for the writer of modulated syllables

Non-modulated states = 27
Modulated states = 18
Trace syllable = 1
46 = Total Prosodynic States (choices) per syllable

Figure 4.
"Prosodic freedom" of the writer or the number of choices for writing syllables with different prosodic numbers. The shape of this matrix is somewhat similar to the normal distribution curve. Exercise of this "freedom" is reduced by all the constraints of English except in poetry, language research, and other special uses.

direction, then at least one stress level difference is observed 90% of the time.[12] This stress difference between two syllables implies that levels of their third prosodic dimension remain constant. A graphic portrayal of how differences in prosodic levels within a sentence can generate 4 stress levels is presented in Figure 5.

Figure 5.
Converting prosodic numbers by difference into relative stress levels for pairs of monosyllabic words in a sentence. Suppose we had no trace value of 1. Then, we could not calculate 4 levels of stress as a maximum difference between a pair of most and least stressed syllables; i.e., $\frac{9-1}{2}=4$. Yet, we know by experiment that 4 levels of stress are perceivable in non-contextual English. This is the rationale for attaching "1" to reduced vowels. It is an arithmetic device for satisfying experimental values.



When we deal with prosodic numbers we consider sums of numbers assigned to perceived levels. Prosodic states operate with permutations of these numbers. A prosodic state is any combination of three levels of perceived pitch, amplitude, and time. Since each of these three parameters has three levels, the total of their permutations $= 3^3 = 27$. This applies to all non-modulated prosodic states. The number of modulated states would equal another 27 were it not impossible for the modulated pitch and force effort cues to work in fast time (Fig. 1A). With medium and slow durations there are $2 \times 3 \times 3 = 18$ modulated prosodic states (Fig. 4). Add to these unity for the singular reduced vowel. The final sum is $27 + 18 + 1 = 46$. Figure 4 also makes it evident that extremely high or low stressed vowels demand the fewest prosodic decisions by the writer while medium stressed vowels maximize the number of decisions.

Discussion of Information in Graphic Design

Prosodynic print carries more of English speech into print than either diacritical marks or standard English orthography. Its information is primarily graphic. One might say that prosodynes are less visible speech than the visible intentions of speech; particularly, the writer's intentions. Because the subjective intentions of the speaker determine emphasis, prominence, and the other information of prosody, clarification of a writer's prosodic intention may reveal substantial amounts of information.

When we look at written language from a strictly graphic point of view, the cues of prosodynic print appear to exploit the limits of distortion of a letter without destroying its recognizability. Each variation of shape of a letter may be counted as a choice in the structure of that letter. Accordingly, the number of choices within the limits of recognizability is a kind of "graphic information." It is this sort of graphic information which is the visual essence of these cues.

The print is designed to look as it sounds. This is accomplished by selecting physical features that occur in both the spoken and written symbols of prosody: up-down markings identify up-down pitch; amount of blackness represents amount of vocal force and effort; extensions of length identify extensions of time; blank white

space stands for silence of pauses. These associations are structured so that foreign readers may more easily identify the prosody of a second language. This isomorphasism can be assessed by comparative tests with diacritical symbols.

Prosodynic dimensions are spatially independent. The occurrence or non-occurrence of one prosodynic cue in no way affects the occurrence of any other cue. As a result displays of a single letter's cues for pitch, apparent amplitude, and time do not interfere with perceptions of contours of intonation or loudness. Spatial independence is an important component of graphic design. Its opposite, conjugality, causes confusion; e.g., when the height dimension of size as a cue for loudness cannot be separated from the elevation of vowels as a cue for pitch in intonation contours.

It is well known that the consonants contribute more than the vowels to our recognition of both aural and written language. The meaning of the sentence below can be read more easily from consonants than from vowels:

*A *E* *I** **I *E *I* *A *I** *A*

J *M *S W *LL DR *V* H *S R *C *NG C *R

This cue system maintains consonantal intelligibility by keeping consonants on the same line. This uniformity fixes the eye on a graphic standard of reference. Reference standards increase the information of stimuli.[13] It is the vowels that carry most of the information in this system. Here, vowels are the principal cues for pitch because vowel sounds are the prime source of perceptions of frequency and intonation in English.

Prosodynic print instructs readers to articulate consonants with different efforts and durations, along with vowels at varying pitch, intensity, and durations. These orthographic contrasts enable readers to visualize transitions from prosodic levels to stress levels at a glance. Stress patterns are in the orthography.

This study observes at least four criteria for increasing the information of notations, the power of written language symbols where "power" means the number of events a symbol might identify:

1. The smaller the linguistic units, the more information they carry; i.e., alphabets give more information than syllabaries.
2. Spatial independence of cues.
3. Multi-dimensionality in contrast to single dimensional cues.
4. A graphic reference standard for perceptual judgment.

Finally, it should be noted that prosodynic print has been used for speech therapy on two patients[14] and in creative poetry.[15] A better understanding of the basic processes involved and on their application calls for continued testing; e.g., on the model for converting prosodic levels into speech levels.

Summary
An orthographic technique for writing English prosody has been developed by distortions of length of letters, differences in darkness, and the elevations of letters, and by varying extensions of white space between words. The three perceived dimensions of prosody (pitch, apparent amplitude, and time) are *numerically* matched by three *independent* graphic dimensions (elevation, darkness, and length). The independence of the discrete graphic symbols are at least as independent as the symbols in the continuous oral system.

1. W. W. Goodwin & C. P. Gulick. *Greek Grammar* (Waltham, Mass., 1958), p. 26. The Greeks attached duration or length to their vowels as a function of the number of consonants that followed the vowel. This was one factor in scanning Greek poetry. Clearly, numerous scanning systems can be written dependent on cue instruction to emphasize this or that cue component of a language.
2. G. L. Trager and H. L. Smith. *An Outline of English Structure* (Washington, 1957), p. 49.
3. John Walker. *On Pronunciation of Proper Names* (Philadelphia, 1808), p. 306.
Joshua Steele. *Towards Establishing the Melody and Measure of Speech to be Expressed and Perpetuated by Peculiar Symbols* (London, 1781), pp. 24, 189-190.
H. A. Gleason. *An Introduction to Descriptive Linguistics*, rev. ed. (New York, 1961), p. 45.
Ernest M. Robson. *The Orchestra of the Language* (New York, 1959), p. 44.
4. Naom Chomsky. *Syntactic Structures* (The Hague, 1957), p. 38; note on prosodic compensation in reading "non-grammatical strings."
Phillip Lieberman. *Intonation, Perception and Language* (Cambridge, Mass., 1967), p. 166. See also reference to "degrees of stress on isolated words," p. 182.

5. At least three levels of perceived pitch (frequently 4 levels) have been observed by many linguists and phoneticians (Lieberman, pp. 171-195). Short duration intervals range from 0.04 sec. to 0. 12 sec.; average durations from 0.20 sec. to 0.28 sec.; long durations from 0.40 sec. to 0.48 sec.; SD = 0.041 sec. For measurements of these periods which give a mean ratio 3:1 = long duration/short duration, see reports by:

G. E. Peterson & I. Lehiste. "Duration of Syllable Nuclei in English," *Jrn. Ac. Soc. Amer.*, XXXII, No. 6, 1960, p. 702.

D. B. Fry. "Duration and Intensity as Physical Correlates of Linguistic Stress," *Jrn. Ac. Soc. Amer.*, XXVII, No. 4, 1955, p. 768.

J. N. Pickett & I. Pollack. "Intelligibility of Excerpts from Fluent Speech," *Lang. and Speech*, VI, 1963, July-Sept., pp. 156-159.

George A. Miller. *Language and Communication* (New York, 1951), p. 74.

A. H. House. "On Vowel Duration in English," *Jrn. Ac. Soc. Amer.*, XXXIII, 1961, No. 9, pp. 1174-1178.

Pierre Delattre. "A Comparison of Syllable Length Conditioning Among Languages," *Sonderdruck aus IRAL*, IV, 3/1966, pp. 186-196.

An amplitude difference of 9db between two syllables in the same linguistic environment equals one loudness level in short English. See the phon scale of loudness level in Harvey Fletcher, *Speech and Hearing* (New York, 1958), pp. 177-194 for tonal loudness levels, and pp. 76-78 for ranges of speech power over 60db from very quiet to extremely loud speech. This range is broad enough to cover three loudness levels in a continuous flow of talk that varies between soft spoken and shouted words. These intensity level differences are standard psychoacoustic knowledge. That the wide db range of talk does not frequently occur in conversation excludes neither its possible occurrence nor the desirability to be able to identify it by notation.

6. Claude Wise. *Applied Phonetics* (Englewood Cliffs, N. J., 1951), pp. 182, 397.

Pierre Delattre. "Comparing the Prosodic Features of English, German, Spanish, and French," *Sonderdruck aus IRAL* Vol. I, 3/1963, p. 194. Delattre has shown, convincingly, the need for graphic representation of suprasegmental information and the inadequacy of numerical identification of levels as vocal instructions. An adequate notation should reach visual-minded people. That this is not a trivial consideration is substantiated by the role of geometry in the history of mathematics: Raymond L. Wilder. *Evolution of Mathematical Concepts* (New York, 1968), pp. 106-109.

Ralph N. Haber. "How we remember What We See," *Scientific American*, 5/1970, pp. 104-112.

7. Ilse Lehiste & Gordon Peterson, "Some Basic Considerations in the Analysis of Intonation," *Jrn. Ac. Soc. Amer.*, XXXIII, No. 4, 4/1961, pp. 420-421.

A. E. Rosenberg. "Effect of Pitch Averaging on the Quality of Natural Vowels," *Jrn. Ac. Soc., Amer.*, XLIV, No. 6, 12/1961, pp. 1593-1594.

8. Pierre Delattre. "A Comparison of Syllable Length Conditioning Among Languages," *Sonderdruck aus IRAL*, IV, 3/1966, pp. 186-196.

P. Denes. "On Statistics of Spoken English, *Jrn. Ac. Soc. Amer.*, XXXV, No. 6/1963, p. 898.

9. Originally prosodynes were presented to the Phonetics, Linguistic, and Voice Science Interest Group in New York City at the December 1965 meeting of the SAA, under the name of "Intonemes." In 1967 Pierre Delattre wrote a letter

suggesting the term "prosodeme." I modified "prosodeme" to "prosodyne" because of the association of energy with "dyne" and energy levels of prosody.
10. Phillip Lieberman. "Some Acoustic Correlates of Word Stress in American English," *Jrn. Ac. Soc. Amer.*, XXXII, No. 4, 1960, pp. 451-454.
Fry, pp. 765-768.
11. G. L. Trager & H. L. Smith. *Outline of English Structure* (Norman, Oklahoma, 1951). Daniel Jones has specified several stress levels for "sense groups" of short English; only two stress levels for long conversation. Evidently, Phillip Lieberman agrees with Jones (*Intonation, Perception and Language*, p. 182). Further support of three to four stress levels in short English comes indirectly from the need to specify six different db levels on the newer sonograph displays of speech spectrographs. The classic loudness scales (Fletcher, Stevens, Garner) also suggest three to four levels of "loudness" as range limits.
12. Lieberman, pp. 453-458; Fry, p. 767.
13. I. Pollack. "Information of Elementary Auditory Displays," *Jrn. Ac. Soc. Amer.*, XXV, July 1953, pp. 765-769.
14. "Intonemic Orthography in Speech Therapy" presented April 1967 to the Pennsylvania Speech and Hearing Association conference in Pittsburgh. Therapy was conducted by Anne Highland at the Speech and Hearing Clinic, University of Pennsylvania Hospital, Philadelphia.
15. Ernest M. Robson. *Transwhichics* (Chester Springs, Pa., 1970).