An Experimental Approach to Lexical Stress in English－Ⅱ

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1. Introduction

This paper is intended as a follow-up study of Soeda (2003) on the question about lexical stress in English, ‘ Is stress really loudness, or pitch, or duration? ’ In my last analysis, I came to the conclusion that pitch is the most important factor, energy is the second, and duration the third. But I also said that it would be necessary to look at more data.

Before we go any further, there are some points to be considered: we must be clear what we mean by these three terms. Technically speaking, loudness, pitch, and duration are all auditory properties, but not acoustic properties we can measure. The term *fundamental frequency* is used for physical measurements, whereas *pitch* refers to perception. The term *stress* is used so loosely and in so many different ways. It is something of a cover term and we always wonder whether it refers to intensity, fundamental frequency, duration, or a combination of these. In other words, stress has proved to be the most difficult to define in purely phonetic terms. However, according to Ladefoged (2001), ‘ In fact, experiments on the perception of pitch have shown that within the range of pitches used by both male and female voices, a change in frequency is directly related to a change in pitch. ... The relation between acoustic intensity and loudness is also nonlinear, but fortunately only slightly so. For all practical purposes we can consider

differences in loudness to be simply related to differences in intensity, reported in dB.' So, in general, this may be equally true for duration as well. And auditory/acoustic consequences of a syllable having received stress are likely to be some combination of increased pitch, length and loudness.

2. Procedure

The material chosen was 20 pairs of English words in which a change of function from noun to verb is commonly associated with a shift of stress from the first to the second syllable. These words were : *abstract, conduct, contract, contrast, convict, desert, digest, escort, export, import, insult, object, perfect, permit, present, produce, record, subject, survey, torment.*

Two educated native speakers (an RP speaker and a GA speaker) were asked to read sentences containing the words above and the readings were recorded on tape. As in the previous experiment, they were asked to say each word in the same frame " Say_____now " to keep to the rate of utterances as constant as possible. Spectrograms of the selected words were made on both CSL-Model 4300B (from Kay Elemetrics Corp.) and PCquirer (from SciConRD) to measure the vowel duration, intensity and pitch which occur in these words. We can ignore the consonant duration ratios, because they are not materially affected by the shift of stress.

I will be using the PCquirer system for duration measurements and CSL for pitch and intensity measurements respectively.

2.1. Acoustic Data[1]

Table 1-1

Measured vowel durations (ms), pitches (Hz) and intensities (dB) for twenty pairs of words produced by an RP speaker, in which a change of function from noun to verb is associated with a shift of stress from the first to the second syllable.

	ms	ms	Hz	Hz	dB	dB
AB-stract	98.8	131.8	193.42	125.28	76.37	74.62
ab-STRACT	91.8	147.2	117.29	190.09	74.88	76.59
CON-duct	95.1	116.4	212.02	141.35	78.51	72.71
con-DUCT	82.9	146.7	117.29	151.03	73.68	77.99
CON-tract	91.9	93.6	200.45	141.35	77.94	70.02
con-TRACT	80.2	134.7	121.15	183.75	73.7	78.74
CON-trast	84.6	121.9	200.45	106.01	78.84	71.29
con-TRAST	77.8	197.2	113.66	167.05	74.56	79.13
CON-vict	90.1	77.4	208.02	117.29	77.84	72.98
con-VICT	85.1	99.7	113.66	151.03	72.84	78.94
DE-sert	123.7	120.7	183.75	117.29	82.05	74.64
de-SERT	101.4	234.7	119.84	128.2	77.49	77.92
DI-gest	229.5	144.4	212.02	136.11	78.12	75.34
di-GEST	157.6	151	128.2	147	74.13	78.13
ES-cort	103.4	162.2	204.17	151.03	78.63	76.03
es-CORT	87	185.7	131.25	190.09	71.68	82.31
EX-port	69.4	196.9	200.45	113.66	81.3	76.04
ex-PORT	71.4	189.4	125.28	159.78	75.06	83.31
IM-port	78.3	138.3	190.09	100.23	82.6	76.93
im-PORT	64.7	172.1	121.15	172.27	78.53	83.29
IN-sult	89.2	68.4	200.45	125.28	82.67	76.53
in-SULT	67.5	79.4	117.29	153.13	75.68	79.1
OB-ject	102.1	94.5	200.45	119.84	77.83	75.15
ob-JECT	82.3	122.8	123.88	167.05	75.95	76.69
PER-fect	162.2	66.1	212.02	121.15	78.89	73.46
per-FECT	144	116.6	100.23	162.13	73.83	77.82
PER-mit	159.9	96.9	208.02	109.16	79.7	74.53
per-MIT	152.5	80.1	121.15	141.35	75.42	78.3
PRE-sent	71.4	43.1	225	121.15	79.61	72.39
pre-SENT	49.9	138.1	116.05	141.35	78.52	79.46
PRO-duce	66.3	112.6	212.02	116.05	80.52	75.39
pro-DUCE	66.3	138.9	123.88	153.13	75.59	85.1
RE-cord	68.9	207.3	204.17	151.03	83.91	77.65
re-CORD	51.7	317.8	116.05	162.13	74.26	84.19
SUB-ject	73.5	108.4	204.17	136.11	80.45	73.88
sub-JECT	50.7	112.4	93.32	143.18	72.35	76.5
SUR-vey	199.3	192.4	216.18	116.05	78.28	68.22
sur-VEY	188.5	347.1	117.29	147	74.21	76.84
TOR-ment	148.2	87.5	245	12.88	78.58	72.14
tor-MENT	135.5	112.7	119.84	147	72.76	72.78

Table 1-1 above shows the acoustic factors (duration, pitch, energy) for the twenty orthographically identical word-pairs in English differentiated by word-stress as nouns (penultimate stress) or verbs (final stress), as spoken by an RP speaker.

Table 1-2 Multiple correlation coefficient[2]

duration	pitch	energy
0.396598	0.972375	0.900587

Table 1-2 above shows, based on the data in Table 1-1, the multiple correlation coefficient of each factor, and clearly indicates that pitch is the most significant factor, and energy the second, and duration the third. Table 1-3 is given for comparison. It shows the multiple correlation coefficient of each factor based on the date from the previous experiment.

Table 1-3 Multiple correlation coefficient

duration	pitch	energy
0.302791	0.922134	0.76625

The t-test[3] based on table 1-1 also confirms the findings.

Table 2-1

Measured vowel duration (ms), itches (Hz) and intensities (dB) for twenty pairs of words produced by a GA speaker, in which a change of function from noun to verb is associated with a shift of stress from the first to the second syllable.

	ms	ms	Hz	Hz	dB	dB
AB-stract	139.9	126.6	162.13	121.15	76.73	75.5
ab-STRACT	79.6	143.7	121.15	131.25	72.11	77.82
CON-duct	132.3	111	155.28	125.28	78.13	74.38
con-DUCT	75.9	115.6	117.29	128.2	69.54	76.18
CON-tract	113.3	111.5	153.13	108.09	78.58	74.13
con-TRACT	70.1	114.8	108.09	125.28	71.79	77.9
CON-trast	97	121.7	147	114.84	76.05	72.28
con-TRAST	72.6	142.5	110.25	116.05	68.32	76.37
CON-vict	107.1	52.6	167.05	119.84	79.44	74.52
con-VICT	83.3	60.7	109.16	134.45	71.83	74.59
DE-sert	93.4	95.1	162.13	131.25	82.23	73.95
de-SERT	86	124.3	111.36	143.18	75.66	78.47
DI-gest	121.9	80.9	134.45	123.88	79.77	77.66
di-GEST	85.3	81.5	119.84	121.15	77.91	79.44
ES-cort	116	158.2	153.13	114.84	79.65	76.78
es-CORT	88.2	152.8	107.04	128.2	70.44	78.76
EX-port	70.7	152.3	116.05	101.15	76.63	74.73
ex-PORT	44.7	131.8	89.63	141.35	69.27	76.97
IM-port	51.4	148.3	145.07	125.28	75.73	74.01
im-PORT	56.1	139.2	103.04	141.35	68.93	76.6
IN-sult	77.2	76.1	143.18	114.84	76.29	74.29
in-SULT	71.4	59.8	97.57	136.11	68.28	76.35
OB-ject	128.8	91.1	141.35	114.84	78.99	75.65
ob-JECT	80.8	114.7	77.1	123.88	74.9	77.75
PER-fect	76.3	57.2	175	113.66	80.13	74
per-FECT	68.9	107.9	119.84	145.07	71.85	79.02
PER-mit	94.4	70.2	183.75	159.78	79.69	74.87
per-MIT	98.2	91.0	125.28	143.18	74.2	74.59
PRE-sent	103.3	71.2	153.13	125.28	80.08	69.7
pre-SENT	54.7	127.2	121.15	134.45	73.27	73.97
PRO-duce	110.2	102.8	180.74	147	82.64	76.8
pro-DUCE	52.3	124.5	131.25	143.18	75.77	76.65
RE-cord	48.9	131.6	153.13	125.28	82.38	75.35
re-CORD	46.9	189.9	109.16	136.11	75.85	77.64
SUB-ject	71.5	89.4	167.05	121.15	79.45	76.21
sub-JECT	57.9	98.6	121.51	134.45	72.27	78.52
SUR-vey	197.6	168.1	167.05	125.28	79.62	75.27
sur-VEY	124.5	229.4	117.29	121.15	71.76	76.26
TOR-ment	119.7	106.2	167.05	125.28	80.26	73.55
tor-MENT	90.8	116.5	128.2	139.56	74.88	75.07

Table 2-1 above shows the acoustic factors (duration, pitch, energy)

for the twenty orthographically identical word-pairs in English differentiated by word-stress as nouns (penultimate stress) or verbs (final stress), as spoken by a GA speaker,

Table 2-2 Multiple correlation coefficient

duration	pitch	energy
0.535736	0.904343	0.862639

Table 2-2 above shows, based on the data in table 2-1, the multiple correlation coefficient of each factor, and clearly indicates, as table 1-2 does, that pitch is most significant factor, and energy the second, and duration the third. Table 2-3 is given for comparison. It shows the multiple correlation coefficient of each factor based on the data from the previous experiment.

Table 2-3 Multiple correlation coefficient

duration	pitch	energy
0.570642	0.969556	0.848173

The t-test[4] based on table 2-1 also confirms the findings.

3. Conclusion

The experiments and statistical analyses conducted on a larger scale than those in the preceding study (Soeda 2003) certainly confirm the last conclusion; that is, as far as lexical stress in English noun/verb pairs is concerned, among the three concomitant factors of stress, pitch is the most important factor, energy is the second, and duration the third in both RP and GA. In other words, the results of the statistical analyses in both experiments show very clearly the existence of a hierarchy of acoustic

factors in a stressed syllable in English. Despite the fact that , from the perceptual point of view, duration is usually regarded as the second factor in the hierarchy (Fry, 1955, 1958, Roach, 1996), intensity is a much more important factor than duration from the productive point of view.

Notes

1. I am deeply grateful again to Dr.Ikuo Sugiman for his generous help and advice in analyzing the data statistically.
2. The correlation coefficient is a measure of linear association between two variables. Values of the correlation coefficient are always between -1 and +1. A correlation coefficient of +1 indicates that two variables are perfectly related in a positive linear sense, a correlation coefficient of -1 indicates that two variables are perfectly related in a negative linear sense, and a correlation coefficient of 0 indicates that there is no linear relationship between the two variables.
3. The t-test based on table 1-1

duration		pitch		energy	
1st syllable	2nd syllable	1st syllable	2nd syllable	1st syllable	2nd syllable
t:4.705714 p(T<=t)7.7E-05	t:-4.19045 p:0.000248	t:24.89238 p:2.88E-16	t:-5.9314 p:4.95E-08	t:10.44353 p:1.3E-09	t:-8.67311 p:2.47E-08

4. The t-test based on table 2-1

duration		pitch		energy	
1st syllable	2nd syllable	1st syllable	2nd syllable	1st syllable	2nd syllable
t:5.617345 p:1.02E-05	t:-3.19085 p:0.002406	t:17.18011 p:2.47E-13	t:-3.70737 p:0.000747	t:17.4289 p:1.9E-13	t:-6.78625 p:8.81E-07

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