

**Articulatory Features, Energy, and
Sound Pressure of the Voiceless Stop
Sounds in English**

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Abstract:

This study aims at investigating the articulatory features of the voiceless stop sounds in American English by the measurement of their acoustic realizations. The following questions will be answered:

- 1- to what extent the phonetic positions of the phonemes of interest affect the articulatory manifestation?
- 2- what are the implications of energy measurements of these phonemes according to their phonetic positions?
- 3- what is the pattern of energy distribution of these phonemes?
- 4- what is the correlation between energy and sound pressure level in the production of these phonemes?

The representing positions of the voiceless stops in American English were chosen and measured by the Computer speech lab (CSL). The study ended up with the following results:

- 1- The energy of these phonemes is high in general although they differ from each other in magnitude according to their phonetic positions.
- 2- The pressure of these phonemes is low in general. Their minimum pressure is negative.
- 3- The correlation between energy and sound pressure level of these phonemes is contrasting in the sense that the more energy the less pressure.

The comparison between aspirated and unaspirated manifestation of these phonemes shows that aspiration is not a crucial factor in increasing their energy although its effect on increasing the maximum pressure is clear.

Key words: Voiceless stop sounds.

الملامح النطقية، وقياس طاقة وضغط الأصوات الوقفية المهموسة في الإنجليزية

أ.د. سمير شريف استيتية

الملخص:

يهدف هذا البحث إلى تشخيص الملامح النطقية، وقياس مقادير طاقة الأصوات الوقفية المهموسة في الإنجليزية، وكيفية توزيع طاقة هذه الأصوات في القناة الصوتية، وقياس ضغطها، والكشف عن العلاقة بين الطاقة والضغط في نطقها.

اختار الباحث عينة من الكلمات الإنجليزية في سياقات ثلاثة: في البداية والوسط والنهاية. وقد استخدم الباحث برنامج CSL الحاسوبي لقياس طاقة هذه الأصوات وضغطها، وكيفية توزيعها في القناة الصوتية عند نطق هذه الأصوات في سياقاتها الثلاثة.

وقد توصل البحث إلى النتائج الآتية:

1. إن طاقة هذه الأصوات مرتفعة، ولكنَّ ضغوطها منخفضة.
2. العلاقة بين طاقة هذه الأصوات وضغوطها علاقة عكسية.
3. لا توجد علاقة بين تفسية aspirated هذه الأصوات وطاقته، ولكنَّ ثمة علاقة تلازمية بين كونها كذلك وزيادة الحد الأعلى من ضغوطها maximum pressure.

مصطلحات أساسية: الوقفيات المهموسة في الإنجليزية

1. Introduction

The categorization of language sounds according to their articulatory features and functions is well known in phonetics. In most cases, phoneticians categorize sounds into two groups: consonants and vowels. Some of them use the terms contoids and vocoids in the phonetic level⁽¹⁾ in lieu of consonants and vowels. In this paper, the terms consonants and vowels will be used.

Consonants' groups are usually based on:

- (1) continuity or stoppage of the air stream
- (2) sound phonation which implies the processes of voicing and voicelessness.

Subgroups are made by gathering two or more of the previously mentioned sound features. For instance, voiceless stop and voiced stop sounds exist in phonetics.

Each one of these two groups - voiceless stops and voiced stops - has common features as well as distinctive features. Phoneticians studied these two groups and other sound groups according to the articulatory and acoustic features. Some concentration has been made on the study of amplitude,

vibration, frequency, sound wave, spectrographs, and some other topics of acoustic phonetics. However, other domains still need to be highlighted such as sound pressure and energy: the amount and distribution in the oral cavity.

2. Problem of the study

This study aims at investigating the articulatory features of the voiceless stop sounds in American English by the measurement of their articulatory and acoustic realizations. The following questions will be answered:

- (a) to what extent the phonetic contexts of the phonemes of interest affect their articulatory manifestations?
- (b) what are the implications of energy measurements of these phonemes according to their phonetic positions?
- (c) what is the pattern of energy distribution of these phonemes?
- (d) what is the correlation between energy and sound pressure level in the production of these phonemes?

3. Importance of the study

Jakobson, Fant, and Halle developed a theory for the analysis

of sounds known as distinctive features⁽²⁾. Jakobson and his colleagues took into consideration some, but not all acoustic features⁽³⁾. Although this theory has been modified, it still lacks some aspects which need to be considered including sound energy (quantity and distribution).

This study may be considered one of a kind because it is the first that tackles sound features of energy quantity, energy distribution in the vocal tract, and sound pressure level. Moreover, the combination between the articulatory and recent acoustic analysis in computer speech lab (CSL) makes the study up to date with the latest research in phonetics.

4. Literature Review

Daniel Jones may be considered the most remarkable pioneer of the study of phonetics in the 20th century. His ‘An outline of English phonetics’ contains lots of innovative descriptions and ideas in English phonetics. The present study got a lot of ideas from this remarkable reference in its theoretical phase.

Roman Jakobson, G. Fant, and Moris Halle in their ‘Preliminaries

to Speech Analysis – The Distinctive Features and Their Correlates’ categorized sound features into fundamental and secondary. The first implies the following: vocalic vs. non-vocalic; consonantal vs. non-consonantal. The second implies envelope features (interrupted vs. continuant; checked vs. unchecked; strident vs. mellow) and resonance features (compact vs. diffuse; tonality features etc). This study got some ideas and terms from this work.

Other studies were considered as important references for this study. The following section lists some of these studies:

1.” On the perception of unreleased voiceless plosives in English” by Bjorn Anderson⁽⁴⁾.

In this study an experiment concerned with the possibility of distinguishing audibly between unreleased glottal stop, and unreleased p, t, and k in English was carried out, with two groups of hearers, one listening by means of earphones, one listening by means of a loudspeaker. The study found that correct identification of all stops largely depended on the way which the sounds were (re)produced and conveyed to the hearers. It also

found that correct identification depended on the quality of the preceding vowel, especially in the case of [p, k]. Under the best listening conditions the glottal stop was identified with considerable accuracy.

2. “Duration of syllable nuclei in English” by Gordon Peterson and Ilse Lehiste⁽⁵⁾.

This study dealt with influence of preceding and following consonants on the duration of stressed vowels and diphthongs in English. It focussed on the voiceless stop sounds. The results of the study showed that voiceless stop sounds had long duration when compared with other consonants.

3. “Multiple features analysis of intervocalic English plosives “ by Thomas Edwards⁽⁶⁾.

This study evaluated the acoustic stop features for automatic stop recognition. Both time-domain and frequency-domain were measured via computer interaction. The results indicated that the acoustic features burst/formant-onset frequency and voice onset time (VOT) were the two most salient features for stop identification. Several additional features were also presented to provide important redundancy for

identification.

The present paper differs from the previously reviewed in terms of its object, content, and results. The referred to studies did not investigate energy, sound pressure level, and the correlation between them.

5. Stop sounds in English

5.1. Criteria

There are six stop sounds in English. Three of them are voiceless [p, t, k] and the rest are voiced [b, d, g]. This study is concerned with the first three sounds. The essential features of this group represent the vertical aspect of each phoneme i.e. being stop and voiceless. The other is the horizontal aspect which includes its phonemic distribution in different speech positions. Aspirated allophones, for instance, represent this horizontal domain.

Since this study is concerned with analyzing the voiceless stop sounds in English, the articulatory description of producing stop sounds needs to be illustrated. Fry states that stop sounds are produced “ with a short silence or near-silence followed by a short burst of noise if the stop is released⁽⁷⁾. One should differentiate between what was

described by Fry as a short silence and what is known in articulatory phonetics as a stop of the air stream behind the point of articulation. The stop of the air stream is not silence. Rather it is a momentarily step of producing stop sounds. This shows the necessity of considering the steps of producing stop sounds as criteria.

In the process of producing stop sounds four successive stages are defined: closure of the passage of the air stream at the point of articulation, stoppage of the air stream, openness of the air stream passage, and explosion. Some stages were dealt with according to the so called 'the most important stage'. According to American phoneticians the stoppage of air stream is the most important stage and accordingly this group is called stop sounds⁽⁸⁾. On the contrary British phoneticians consider the explosion the most important stage. Accordingly they call these sounds plosives⁽⁹⁾.

This study takes the holistic approach and considers four stages as criteria of stop sounds instead of preferring one criterion over the others. However, this study still uses the name of stop sounds not

because considering the stoppage of airstream the more important stage. We know that distinctive characteristics make any subject distinct from other subjects. In this sense the stoppage of the air stream makes it distinct because the air does not originally stop; it is always moving. Moreover, explosion of the air stream is a result of its being blocked at the point of articulation.

With regards to the steps of producing stop sounds as criteria may be contradicted by the idea that some of these steps may be declined. This is clear in some Americans' pronunciation of the word stamp without explosion i.e. the last stage of pronouncing [p] when the whole word occurs in the final position of the sentence. This contradiction is built on the idea that criteria should not be missed. It is necessary to clarify this point. Let us first say that this case makes the sound incomplete stop sound⁽¹⁰⁾. The explosion is declined because the speaker makes sure that the receiver understands him/her depending on his/her phonemic perception⁽¹¹⁾. This sense is emerged according to Gestalt psychology by the so called circle closure of any subject which means filling in the

gaps in perception⁽¹²⁾. The process of closing the circle of any subject makes us aware of the entire subject even when it is incomplete. The loss of any stage of the subject will be completed by closing the circle.

However, the explosion of the stop sound may be removed to another point of articulation. Daniel Jones states that “this happens in normal English when a plosive consonant is immediately followed by another plosive or by an affricate. Thus in the usual pronunciation of such words as an act [ækt], picture [piktʃə] «⁽¹³⁾.

5.2. Voiceless stops: Articulatory features

There are two types of articulatory features in American English. The first is phonemic in the sense that these features are essential even when some are changed in pronunciation. This is clear in this group by its being stop, voiceless, anterior or back place of articulation. The second is allophonic which represents the secondary features.

Compact vs. Diffuse

There are two anterior sounds of the voiceless stop sounds in

American English [p, t] and the third is back [k]. It is clear that [p] is bilabial, [t] is apico alveolar, and [k] is velar.

Jakobson, Fant, and Halle in their distinctive features theory described the sounds involving a stricture relatively far back in the oral cavity as diffuse whereas their opposites as compact⁽¹⁴⁾. Accordingly “the difference between compact and diffuse lies in the relation between the volume or resonating cavities in front of the narrowest stricture and those behind the stricture. The velars and palatals are more compact than the consonants articulated in the front part of the mouth “⁽¹⁵⁾. In this sense [k] is considered as compact whereas [p, t] are diffuse.

The differentiation between diffuse and compact sounds according to acoustic criteria makes the difference clear between them. This does not lead to reject the importance of this difference. It only means that the influence of this difference is clear cut. In this case the study of energy, sound pressure level, and the correlation between them will be useful. Sommerstein states that “the Jakobsonian system distinguished velar from palatal consonants by

the feature ‘compactness’ or its mirror image ‘diffuseness’, so that if a velar consonant became palatal, its specification for this secondary articulation in, say, a dental or bilabial consonant became palatal, its specification for this feature would be taken to have changed”⁽¹⁶⁾.

The comparison between diffuse and compact English phonemes should not restrict the difference between them according to front/back points of articulation unless we know the correlation between their acoustic features and their being front or back phonemes. This means it may be more significant if the connection between front or back point of articulation and the phoneme energy and pressure is being made. The novelty of this research paper lies behind the point that it correlates between articulatory and acoustic aspects of the voiceless stop sounds in English.

Aspirated vs unaspirated

Aspiration has been defined as “the audible breath which may accompany a sound articulation, as when plosive consonants are released. It is usually symbolized by

a small raised ^[h] following the main symbol “⁽¹⁷⁾. This definition implies voiced and voiceless stops. The former are not aspirated in English because they have a reasonable degree of energy which makes them audible. The mechanism of voicing makes them in contrast with the aspirated voiceless stops since the accompanying ‘audible breath’ strengthens them and makes them in a high degree of audibility. This ‘audible breath’ is a puff of air which according to Lass makes the voiceless stop sounds fortis ⁽¹⁸⁾. The puff of air is apparently visible on the spectrograms of voiceless stops. It shows up a shading covering a wide frequency range, immediately preceding the vowel ⁽¹⁹⁾.

However, voiceless aspirated stops [p, t, k] can be distinguished from each other according to their phonological contexts whereas their degree of aspiration may also occur according to the situation of utterance.

It may not be efficient to consider only the articulatory mechanism of aspiration as a way of making voiceless stops fortis. We have to cope with this factor according to its acoustic phase so that by measuring its degree of energy and pressure

we can decide whether or not it is fortis and to what degree of fortress it is. Without this measurement categorizing voiceless stop sounds beneath the umbrella of fortis sounds may be in lack to strict and specific degrees of strength and fortress.

Phoneticians discussed the relation between aspiration and glottal openness. MacKay for instance states that initial voiceless consonants begin with wide open state of glottis⁽²⁰⁾. Catford gives a detailed description for articulatory and acoustic phases of this problem and states that “modern techniques of glottography and laryngoscopy show that unaspirated voiceless sounds have a narrowed (though not completely closed) glottis, while aspirated sounds have a more or less widely open glottis⁽²¹⁾. This makes the relation between the openness of glottis and utterance of the voiceless stop sound clear and accurate.

Other allophonic features

There are common allophonic features in the voiceless stop sounds in English. One of the most common features is pronouncing two of this group emphasized. When [t] and [k]

are preceded by a back vowel, the dorsum of the tongue will get raised toward the back area of soft palate to assimilate the back vowel. It is known that [k] is velar which means that its point of articulation is from the velum. Accordingly, the tongue will go back up to the last edge of the velum or even to the uvula. The emphasis of [t] differs from that of [k]. When pronouncing [t] in not, shut, subtle for instance, the tongue goes back to the velum. This means that emphasizing [t] makes it velarized whereas emphasizing [k] makes it post velarized or even uvularized.

One of the most common allophones in American English is pronouncing [t] as a glottal stop in the final environments of fat and not. There is another allophone for [t] in the middle position such as better. It is pronounced as a trill sound.

Daniel Jones referred to nasal plosives. This occurs in the phonetic environment when the voiceless stop sound [t] for instance, is followed by a nasal as the sequence of [tn] in mutton [mʌtn] « The explosion ... is not formed by the air escaping through the mouth, but the mouth closure is retained and

the explosion is produced by the air suddenly escaping through the nose at the instant when the soft palate is lowered for forming the nasal cavity»⁽²²⁾.

Jones also referred to the lateral explosion which occurs in the co-articulation consisting of t+l [tl] as is clear in little⁽²³⁾.

6. Method

The theoretical part of this study is descriptive. It depends to some extent on the related literature. The articulatory features were described according to the phonemic analysis. To meet the objectives of the study three phonetic positions of the voiceless stop sounds of English have been stated: first, middle, and final. The minimum and maximum points of energy and sound pressure level were measured by the computer speech lab (CSL).

The words in table 1 represent three phonetic positions of the voiceless stop sounds in English. The measurement of energy and sound pressure were generated based on the pronunciation of these words.

Table 1
Voiceless stop sounds in English

[p]	[t]	[k]
put	ten	King
suppose	protection	Making
stop	cat	Make

The glottal stop was excluded from this study because it is not considered a phoneme in English⁽²⁴⁾. The difference between the phonation of glottal stop and the phonation of voiceless phonemes should be highlighted although it has been considered a voiceless stop in some works in phonetics⁽²⁵⁾.

In the production of the glottal stop the vocal cords close the passage of the air stream. This way is completely different from the two aspects of phonation: voicing and voicelessness. In the former the vocal cords come close to each other without closing the passage of the air stream.

This makes them vibrate whereas they separate from each other when producing the voiceless sounds, so that the air stream freely goes between them. In this case the vocal cords do not vibrate⁽²⁶⁾. Accordingly the way of producing the glottal stop makes it different from the voiced and voiceless sounds. The data was statistically analyzed. The methodology of this study combines between the experimental and statistical analysis.

7. Results

7.1. Energy results

Two dimensions of energy were studied in this paper: the energy quantity of each phoneme in three phonetic positions (first, middle, and final). The other dimension is 'energy distribution'. The following discussion will go over the two dimensions.

(a) Energy Quantity

Energy is defined as "the ability of one system to do work on another"⁽²⁷⁾. The energy amount of each sound depends on its essential and secondary features and on its phonetic position. Table 2 shows the minimum and maximum energy in the vocal tract of each one of the voiceless stop sounds, its mean and standard deviation.

Minimum energy refers to the

lowest amount of energy in the adjacent chambers in the oral cavity, whereas maximum energy refers to the higher point of energy distribution of the oral cavity.

The mean refers to the total of the two limits (maximum and minimum) divided by two. Energy results in table 2 can be analyzed as follows:

Energy quantity of [p]

The minimum energy of the bilabial voiceless stop [p] is in the first position of put (31.52 db), despite the fact this phoneme is aspirated in this position. The highest amount of energy of this phoneme is in its final position in shape (62.42 db). The difference between the other two positions is 3.13 db.

Table (2)
Energy of voiceless stops in English

No	Sound distribution	Minimum energy	Maximum energy	Mean (db)	Standard deviation
1	[p] in put	31.52	59.96	41.77	8.98
2	[p] in suppose	41.75	56.83	46.76	5.64
3	[p] in shape	40.97	62.42	49.91	6.50
4	[t] in ten	34.06	58.69	50.30	14.07
5	[t]in protection	31.95	58.20	44.14	10.13
6	[t] in hat	37.91	52.79	43.93	5.09
7	[k] in king	34.47	67.01	53.61	14.37
8	[k] in making	52.60	57.78	55.18	2.09
9	[k] in make	38.84	55.89	46.20	5.13

What has been mentioned in the last two paragraphs means that the significant difference between minimum and maximum points of energy occurs when this phoneme comes in the first position. The difference between the two points is 28.44 db (59.96 – 31.52). This significant amount explains the high standard deviation of 8.98 which means that there is a kind of discrepancy of energy amounts between the adjacent rooms in the oral cavity.

Discrepancy between minimum and maximum points of energy occurs when this phoneme is in the final position so that it appears to be 21.45 db (62.42 – 40.97 = 21.45).

Energy quantity of [t]

The minimum energy of the apico alveolar voiceless stop [t] is in the middle position of protection whereas its highest amount of energy is in the first position of ten. The high degree of aspiration in this position needs a high degree of energy. This is clear in the pronunciation of ten.

When we differentiate between the amounts of the minimum energy of this phoneme we don't find great differences among them. The same result can be said about the

maximum amounts of this phoneme since there are no great differences between them.

Energy quantity of [k]

The results of energy of the voiceless velar stop [k] were as follows: The minimum energy of this phoneme (in its phonological distribution) is in the first position of king in spite of it being aspirated. The amount is 34.47 db. The difference between the other two sequences is noticeable (52.60 – 38.84 = 13.76).

The highest value of maximum energy of [k] occurs in its first position of the word king (67.01 db); given that it also scores the lowest value of minimum energy compared to all other positions. It is apparent that aspiration increases its maximum amount of energy but it does not increase its minimum amount.

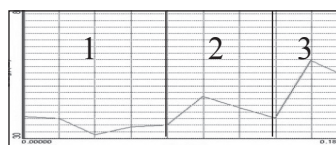
(b) Energy distribution (ED)

The term 'energy distribution' refers to the way the phoneme energy is distributed in the adjacent chambers of the oral cavity. It is mainly related to the manner of distributing energy. It can be described as the quality of distributing the quantity of energy.

Energy distribution of [p]

As is clear in figure 1, the energy of [p] in put can be divided into three main areas illustrating energy distribution in the oral cavity. In the first area, the line of distributing energy is initiated at a low level and is ended at even a lower level. In the second area, the line moves up without realizing important difference in energy distribution between the two areas. On the contrary, the line in the third area is raised up over the middle of y – axis which means that energy of this area is not commonly high although it can be considered high when only compared with the other two areas. It is clear that aspiration does not have a great effect on increasing the energy of this phoneme.

Figure 1
ED of [p] in put



Energy distribution of this phoneme in suppose considerably seems to be stream-lined in the middle position. The line of energy distribution is initiated from a

lower point beneath the first third of y – axis, then it gradually goes up to its last height, and finally it goes down few movements which have no effect on reducing the trace of the last height (figure 2).

With exception to the difference between the first and the final positions, there are no substantial differences in energy distribution between the adjacent chambers in the vocal tract when this phoneme [p] occurs in the middle.

Figure 2
ED of [p] in suppose

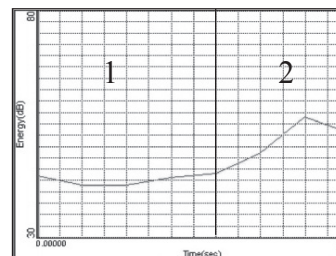
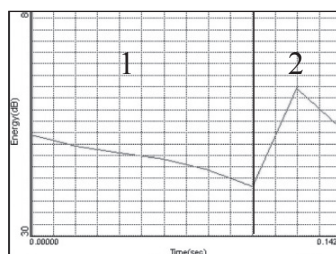


Figure 3 shows that energy distribution of this phoneme in shape is formed in two areas in the oral cavity. They clearly seem to be different in their capacity, magnitude, and fall. The line of energy distribution starts from beneath the middle of y – axis and it gradually falls toward the end of area 1. According to this gradual fall, the difference between the adjacent chambers in energy distribution is not evident in this area.

The line of energy distribution in the second area starts from the end of area 1, and instantly reaches a high degree then suddenly goes down with a sharp fall. This instant increase illustrates the end of pronouncing [p] in shape. The two areas in figure 3 clearly illustrate what has been said about the process of pronouncing [p] with two consecutive but closely connected stages.

Figure 3
ED of [p] in shape



The following can be stated concerning the results of energy distribution of [p] in its three positions:

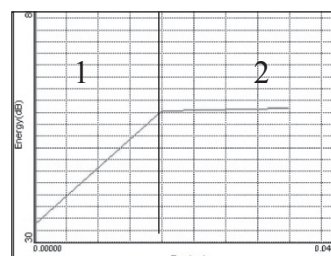
1. The minimum energy is spent in the beginning of pronouncing this phoneme, and then it is increased in later stages.
2. Energy seems to be horizontally spread in each first stage of distribution, while it seems to be vertically narrow in the last stage.
3. Energy of this phoneme is low

because it is diffused and it was not affected by aspiration. This clearly means that aspiration has no effect on increasing the energy of diffused phonemes.

Energy distribution of [t]

Energy distribution of [t] in ten seems to be blocked in two main and wide chambers. It starts from a very low point in chamber 1 but it rapidly goes toward a point over the middle of figure 4. This means that when pronouncing [t] a reasonable amount of energy is spread and it covers 1/4 of this area. The room of energy distribution in area 2 is wider than that of area 1. It covers more than 1/2 of room 2. This means that energy distribution of [t] in the first phonetic position continues to increase from the starting point until the end of pronunciation (figure 4).

Figure 4
ED of [t] in ten

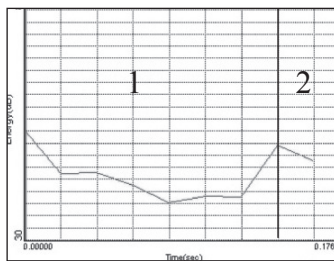


On the contrary, energy of [t] in protection seems to be horizontally distributed into conflicting rooms. As is clear in figure 5 energy of the first area takes the form of an

undercut. However, this room is wider than the second. But both of them have no vertical dimension. This means that energy of [t] in the middle position starts from a low point and continues to be low until the end of pronunciation.

Figure 5

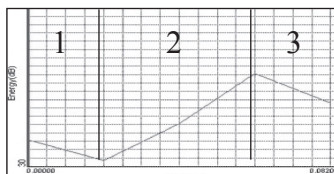
ED of [t] in protection



Energy distribution of [t] in hat seems to be different from what was observed in the other positions. Energy starts from a lower point on y –axis (figure 6) and falls down toward a narrow passage over zero on x – axis. This is clear in chamber 1 and although energy straightly goes up but it does not fill a wide passage in chamber 2. In chamber 2 the line of energy falls down for few steps. This means that energy of [t] in the final position does cover a wide passage in figure 6.

Figure 6

ED of [t] in hat



It may be concluded from the results that the distribution of this

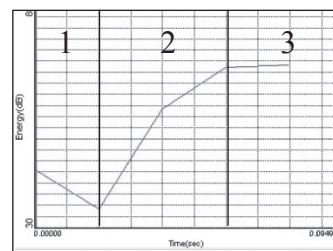
phoneme is affected by diffusion and aspiration. In other words, when the phoneme is diffused, energy distribution is not organized whereas when the phoneme is aspirated, the energy distribution is stream lined.

Energy distribution of [k]

Energy distribution of [k] in king starts from a lower point on y – axis and falls toward a much lower point. This is clear in area 1 in figure 7. In areas 2 and 3 the line of energy distribution is raised to a higher degree and continues to rise in area 3. This increase may be explained by the fact that [k] is velar (diffuse) and at the same time it is aspirated.

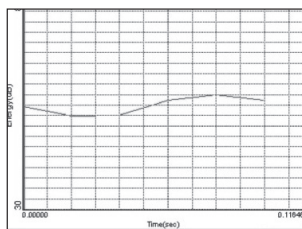
Figure 7

ED of [k] in king



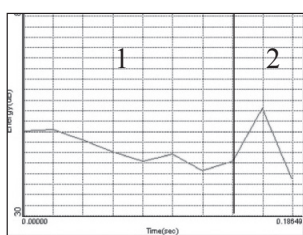
Energy distribution of [k] in making shows that it starts from a high point on y – axis and continues to rise until the end of pronouncing the word making. The line goes through figure 8 like a wave.

Figure 8
ED of [k] in making



On the contrary, energy distribution of [k] in make starts above the end of the first third of y – axis and continues waving in a wide spread manner (figure 9). Although energy is higher in area 2, but it does not go over the middle. The ED seems to be line streamed only in these two positions.

Figure 9



Finally, we may conclude that energy distribution of the phoneme [k] is apparently affected by its being compact and aspirated only when it is in the first and middle positions.

8.2. Results of Sound Pressure Level (SPL)

Pressure is defined as “the ratio of force to area”⁽²⁸⁾. There are levels of pressure, the first is the atmospheric pressure which can be represented by the illustrated figures, the other is the negative pressure which represents the amount of pressure below zero on X - axis in the illustrative figures. Negative pressure is the amount of pressure below atmospheric pressure⁽²⁹⁾. Table 3 includes the amounts of SPL of the voiceless stop sounds.

Table 3
Pressure sound level of voiceless stop sounds in English

No	Sound distribution	Minimum pressure	Maximum pressure	Mean (db)	Standard deviation
1	[p] in put	- 20.75	29.77	- 7.96	7.40
2	[p] in suppose	- 17.56	28.05	- 0.97	9.11
3	[p] in shape	- 17.86	23.33	5.19 -	8.55
4	[t] in ten	- 21.88	11.63	3.49 -	5.63
5	[t] in protection	- 12.80	27.37	8.70	6.37
6	[t] in hat	- 12.85	25.46	0.58	8.14
7	[k] in king	- 19.09	18.05	- 4.94	5.46
8	[k] in making	- 6.18	34.04	13.07	7.93
9	[k] in make	- 29.14	9.98	- 15.6	8.68

When examining the amounts of SPL in table 3 we find that the minimum pressure of all positions of the voiceless stop sounds in English is negative. This means that as soon as the air stream hits the point of articulation, pressure is reduced below atmospheric pressure and starts to make suction pressure in the opposite direction.

To illustrate this idea, let us take the minimum pressure of [p] in put (- 20.75 db); when the pressure falls down to zero the air stream moves to the opposite direction with a power of 20.75 db due to pressure suction, hence it has been called negative pressure. The following is discussion for the maximum SPL of each one of [p, t, k].

Sound Pressure Level of [p]

The highest value of maximum SPL of [p] occurs in put (29.77 db), given the fact that this phoneme is aspirated in this position. Followed by the value of maximum pressure of [p] in suppose (28.05 db). This phoneme is still aspirated in suppose, yet the aspiration is not as much as that in put. Sound pressure level of that phoneme in shape is 23.33 db. We can end up with the result that SPL of this anterior phoneme is

increased by aspiration when in the first and middle positions.

Sound Pressure Level of [t]

The highest value of maximum SPL of [t] occurs in its first position as in protection (27.37 db). This phoneme is aspirated in this position but not as much as the aspiration of that in ten. The value of maximum SPL in the latter is 11.63 db. This apparently means that aspiration did not increase the pressure of this phoneme.

One can theoretically expect that the (SPL) of this phoneme in the final position of [t] in hat may be the lowest. Surprisingly, it was in the second order. This means that the final position of this phoneme did not make its SPL as weak as expected.

Sound Pressure Level of [k]

The highest value of maximum SPL of this phoneme is obtained in its middle position of making (34.04 db), followed by that in first position of king (18.05 db). Although this phoneme is followed by a high front vowel [i] in the two words, the difference is huge between the two positions. This means that the following vowel

has no effect on this phoneme. The lowest value of maximum SPL of [k] is obtained when it is in the final position of make (9.98 db).

Conclusion

The results of this paper can be summarized in the following:

1. Energy of the voiceless stop phonemes in American English is high in general, but they differ from each other in magnitude. The highest energy is that of [k] in the middle position of making (55.18 db), whereas the lowest energy is that of the first position of [p] in put (41.77 db).
2. The pressure of these phonemes is generally low. The mean pressure of [k] in making (13.04 db) is the highest. The pressure of other positions is clearly low.
3. The minimum pressure of all positions of these phonemes is negative in the sense that it is reduced below atmospheric pressure i.e. suction pressure.
4. The correlation between energy and pressure of this group is negative in the sense that the more energy the less pressure in all positions of these phonemes.
5. Comparison between aspirated and unaspirated pronunciation of these phonemes clarifies that their aspiration is not a crucial factor in increasing their energy. On the other hand, the effect of aspiration is clear on increasing their maximum pressure.
6. It is highly recommended that phonetic and linguistic analysis in general be carried out using computer speech lab (CSL) due to its accuracy. This study provides an applied technical aid for teaching English as a first and second language through providing insight into understanding acoustics of English.

Endnotes

1. see for instance: Charles Hockett . A Manual of Phonology. Baltimore, Waverly Press, Inc., 1955, p 150.
- & Kenneth Pike. Phonetics. Ann Arbor, The University of Michigan press, 1971, p 78.
- & John Catford. Fundamental Problems in Phonetics. Indiana University Press, 1975, p. 213.
2. Roman Jakobson, Gunnar Fant, and Morris Halle. Preliminaries to Speech Analysis – The Distinctive Features and Their Correlates. The MIT Press, 1972.
3. The study of energy for instance was not implied in this work.
4. Bjorn Anderson “On the perception of unreleased voiceless plosives in English “, In Language and Speech, volume 3, # 2, 1960.
5. Gordon Peterson, and Ilse Lehiste” Duration of syllable nuclei in English “, in The Journal of the Acoustical Society of America, volume 32, issue 6, 1960.
6. Thomas Edwards. “Multiple features analysis of intervocalic English plosives “, in The Journal of Acoustics, volume 69, issue 2, 1981.
7. D. B. Fry . Physics of Speech, London, Cambridge University Press, 1979, p 107.
8. for instance: John Catford, *ibid*, p. 213 – 214.
9. for instance : Daniel Jones. An Outline of English Phonetics, Cambridge, W. Heffer Co., 1956, p. 183.
10. Daniel Jones, *ibid*, p. 578.
11. Elbert Moses used an alternative term i.e. phonemic sense. see: Elbert Moses. Phonetics – History and Interpretation. N.Y., Prentice – Hall, Inc., 1964, p. 103.
12. Idella Evans, and Ron Murdoff. Psychology for a Changing WorldN. Y., John Willey and Sons(2nd ed), 1978, p 466.
13. Daniel Jones, *ibid*, p.153.
14. Roman Jakobson et al. p27.
15. *ibid*, p 27.
16. Alan Sommerstein. Modern Phonology. University Park press, 1977, p.95.
17. David Crystal. A Dictionary of Linguistics and Phonetics, 1985, p 24.
18. Roger Lass. Phonology – An Introduction to Basic Concepts. Cambridge University Press, 1985, p177.
19. *Ibid*, p 178.
20. Ian MacKay. Introducing Practical Phonetics. Boston, Little, Brown and Company, 1978, p 131.
21. John Catford. Fundamental Problems in Phonetics. Baltimore, Indiana University Press, 1955, p 112.
22. Daniel Jones, *ibid*, p 156.
23. Daniel Jones, *ibid*, p 157.
24. Daniel Jones, *ibid*, p 150.
25. John Catford, *ibid*, p 214.

26. John Catford, *ibid*, p 214.
27. McGraw – Hill Encyclopedia of Science and Technology (5th ed). N.y., McGraw – Hill Book Co., 1982, volume 5, p. 72.
28. McGraw – Hill Encyclopedia of Science and Technology N.y., McGraw – Hill Book Co. (5th ed). 1982, volume 10, p745.
29. Daniel Lapedes (ed). McGraw-Hill Dictionary of Scientific and Technical Terms N.Y., McGraw-Hill Book Co. ,(2nd ed). 1978, p 1075.

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