

## Lombard Speech Effects on the Production and Perception of Plosives

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### Abstract:

In the presence of noise, the characteristics of speech are changed which is known as the Lombard effect. This effect is perceptually felt with an increase in intensity of speaking. These changes in the characteristics of speech production are to ensure intelligible communication in noisy environments. These changes also result in the performance degradation of speech systems like speaker recognition and speech recognition. Human speech production mechanism is affected by this phenomenon.

Acoustic and auditory changes occur when a speaker modifies his/her vocal output to increase the vocal effort and to articulate in a more precise manner for better communication. The Lombard effect increases the degree of speech intelligibility unlike other levels of noise pollution.

This study attempts to assess the effect of this phenomenon on the production and perception of plosives of English, Standard Arabic and Baghdadi Arabic. Certain acoustic tests will be conducted on English and Arabic speakers with full computerized analysis of data.

**Keywords:** Lombard speech, intelligibility, plosives, acoustic features.

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## تأثير ظاهرة لومبارد على إنتاج وإدراك الأصوات الانفجارية

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### ملخص البحث:

تتغير خصائص الكلام في وجود الضوضاء وهو ما يعرف بظاهرة لومبارد، ويتم إدراك هذه الظاهرة من خلال الزيادة الواضحة في شدة الصوت، ويعزى سبب التغيرات الحاصلة في خصائص الكلام الى ضمان التواصل المفهوم في البيئات الصاخبة، تؤدي هذه التغيرات الى تدهور الاداء في أنظمة الكلام مثل التعرف على المتكلم والتعرف على الكلام، وتتأثر آلية إنتاج الكلام البشري بهذه الظاهرة.

تحدث التغيرات الصوتية والسمعية عندما يقوم المتحدث بتعديل الناتج الصوتي لغرض زيادة الجهد الصوتي والنطق الصحيح من أجل تواصل أفضل، وتقوم ظاهرة لومبارد بزيادة درجة وضوح الكلام على العكس من مستويات التلوث الضوضائي الأخرى.

تحاول هذه الدراسة تقييم تأثير هذه الظاهرة على إنتاج وإدراك الأصوات الانفجارية في اللغة الانكليزية واللغة العربية الفصحى واللهجة البغدادية، وسيتم إجراء اختبارات صوتية معينة على عدد من متحدثي اللغة الانكليزية والعربية مع تحليل البيانات باستخدام برنامج حاسوبي.

## 1. Introduction:

Speech is a highly sophisticated mechanism entrusted to human beings only. Human speech or the degree of intelligibility can be easily affected by noise, and the phenomenon that measures this effect is called Lombard effect. Etienne Lombard (a French otolaryngologist and surgeon) discovered in 1911 the Lombard effect which is an involuntary vocal response by speakers to the presence of background noise, in which a person's voice is raised in response to an increase in the noise amplitude. To communicate effectively in noise, a speaker must modify the acoustic properties of the speech signal (Lombard, 1911: 101-119).

Lombard speech includes not only an increase in amplitude, but also a rise in pitch and other spectral changes, and a lengthening of word duration. Some of these additional forms of noise-dependent signal changes associated with

the Lombard effect have also been found in other taxa (Brumm and Zollinger, 2011: 11).

The Lombard effect on speech depends on the environment, speaker and the context of speech communication. This phenomenon is due to hampering self-feedback and not just speaking in the presence of noise. The self-feedback can be hampered by various types of noise ranging from a low intensity air-flow noise to a high intensity fighter cockpit noise. The resulting instability is compensated by modification of the speech produced, which is termed the Lombard effect speech. Analysis of the Lombard effect speech signal is based on time domain properties such as duration of voiced and unvoiced segments, and spectral domain properties such as spectral tilt and formants (Bapineedu et al., 2009: 1091-1094).

Summers et al. (1988: 2-12) studied intelligibility of utterances under the Lombard effect. Speakers increase their vocal levels in the presence of a loud background noise and make several vocal changes in order to improve intelligibility of the speech signal. It was shown that the intelligibility of Lombard speech increased up to a certain level of noise, when presented at a constant speech-to-noise ratio, and sharply decreased when speech took the form of shouting. The primary purpose of Lombard effect is to increase speech intelligibility in communication with other speakers in noisy environments.

Patel and Schell (2008: 209-220) investigated the influence of linguistic content on the Lombard effect. They found that at moderate noise levels, most word types appeared to be uniformly boosted in fundamental frequency ( $F_0$ ), intensity, and duration.

The degree of comprehensibility of speech is intelligibility, and noise in physics is a random and persistent disturbance that obscures or reduces the clarity of a signal (AHD, 2011).

Dursiala and his colleagues (2011: 7) conducted experiments to examine the intelligibility differences of clear and conversational speech and to objectively analyze the acoustic properties leading to these differences. The results showed that the fundamental frequency ( $F_0$ ) tended to be higher in clear speech than in conversational speech. The intensity of clear speech was high compared to conversational speech.

Zhao and Jurafsky (2009: 1) examined monosyllabic words of high and low frequency of use in both normal and Lombard speech styles. The results suggest that different aspects of speech production may account for the strengthening of speech in noise and in low-frequency words.

An interesting experiment was conducted by Fricke (1970: 53-57) where syllable duration was measured in varying noise volume. The experiment demonstrated that the ear monitors the vocal output, and syllable duration

appeared to increase linearly with the introduction of noise in the feedback channel.

Heracleous, et al. (2011: 4) proved that the Lombard effect played an important role not only in audio speech but also in visual speech production. The experimental results of this study show that when visual speech is produced in noisy environments, the visual parameters of the mouth/face change. As a result, the performance of a visual speech recognizer decreases.

**2. Aim of the Study:**

This study aims at exploring the effect of Lombard speech on the production and perception of plosives of English and Arabic speakers.

**3. Materials and Methods:**

In order to conduct the tests of this study, eight subjects (four speakers of English and four speakers of Arabic) were chosen to evaluate acoustic and auditory changes in their speech in a conversation. The materials were three sets of 10 phonetically balanced sentences of English, Standard Arabic and Baghdadi Arabic. Speech was analyzed in computer to identify the changes that occur between normal speech and Lombard speech.

**4. Plosives in English and Arabic:**

In phonetics, plosives are formed by creating a complete closure at some point in the vocal tract, behind which the air from the lungs is compressed until the closure is abruptly released so that the air explodes outwards. Since the soft palate is raised, the air cannot escape through the nasal cavity. Plosives have a very brief friction burst when they are released, which is not usually heard, but is responsible for the "popping" quality of plosive releases (Gussenhoven and Jacobs, 2005).

The importance of plosives comes from the fact that at least some sounds of plosives are found in every known language spoken by humans. The English plosives are six: voiceless /p, t, k/ and voiced /b, d, g/, as shown in Table (1):

Table (1) Plosives in English

		<b>Bilabial</b>	<b>Alveolar</b>	<b>Velar</b>
<b>Plosive</b>	<b>Voiceless</b>	<b>p</b>	<b>t</b>	<b>k</b>
	<b>Voiced</b>	<b>b</b>	<b>d</b>	<b>g</b>

Baghdadi Arabic plosives are nine in number. These plosives are voiceless /p, t, k, q, ʔ/, the voiced /b, d, g/ and the emphatic ones / ʔ , /, as shown in Table (2):

Table (2) Plosives in Baghdadi Arabic

		Bilabial	Dental-Alveolar	Velar	Uvular	Laryngeal
Plosive	Voiceless	p	t	k	q	ʔ
	Voiced	b	d	g		
	Emphatic		ṭ ḏ			

There is a variation in the manifestation of plosives depending on the varieties of language. There are certain characteristics of plosives that are changeable depending on their position in the utterance, for example, plosives affect the length of a syllable according to whether they are voiced or voiceless. Also, the release of plosives depends upon their position in the word.

## 5. Data Collection and Analysis:

In order to measure the effect of Lombard speech on plosives, the study will tackle three sets of 10 phonetically balanced sentences of English, Standard Arabic and Baghdadi Arabic. These sentences are taken from daily conversations and newspapers.

### 5.1 Collected Sentences:

- The English set of sentences is as follows:
  1. The stray cat gave birth to kittens.  
/ ðə'streɪ 'kæt 'geɪv 'bɜ:θ tə 'kɪtɪnz /
  2. Pages bound in cloth make a book.  
/ 'peɪdʒɪz 'baʊnd ɪn 'klɒθ 'meɪk ə 'bʊk /
  3. Boards will warp unless kept dry.  
/ bɔ:dz wɪl 'wɔ:p ən'les 'kept 'draɪ /
  4. Rugs are better to be kept dry.  
/ rʌgz a: betə tə bɪ 'kept 'draɪ /
  5. The cigar burned a hole in the desk top.  
/ ðə sɪ'ga: 'bɜ:nd ə 'həʊl ɪn ðə 'desk 'tɒp /
  6. Glue the sheet to the dark blue background.  
/ 'glu: ðə 'ʃi:t tə ðə 'dɑ:k 'blu: 'bækgraʊnd /
  7. The box was thrown beside the parked truck.  
/ ðə 'bɒks wəz 'θrəʊn bɪ'saɪd ðə 'pɑ:kt 'trʌk /
  8. The small pup gnawed a hole in the sock.  
/ ðə 'smɔ:l 'pʌp 'nɔ:d ə 'həʊl ɪn ðə 'sɒk /

9. The ship was torn apart on the sharp reef.

/ ðə 'ʃɪp wəz 'tɔ:n ə'pɑ:t ɒn ðə 'ʃɑ:p 'ri:f /

10. The source of the huge river is the clear spring

/ ðə 'sɔ:s əv ðə 'hju:dʒ 'rɪvə z ðə 'klɪə 'sprɪŋ /

• The Standard Arabic set of sentences is as follows:

1. /'ʔafham 'wɪdʒhat 'naʔarak ta'ma:man/

(I perfectly understand your point of view.)

2. /'jabdu: 'ʔanna t'ʔifla ʔa:ʔib min wa:lɪdatiha:/

(It seems that the baby girl is angry at her mother.)

3. /qad ja'ku:nul dʒawu 'mumʔiran 'ʔadan/

(It might rain tomorrow.)

4. /'ka:na 'kari:m jas'tamɪʃ ʔila lmu'si:qa:/

(Kareem was listening to music.)

5. /jata'nazzah ulʔaʔfa:l ʃala ʔiffat innahar/

(The children stroll on the river bank.)

6. /ta'na:m uʔʔju:r mu'bakkiran/

(Birds sleep early.)

7. /'na:qafa ʔahmad ʔiqтира:ħa:tihi biħuʔu:r ʔaʃdiqaʔih/

(Ahmed discussed his suggestions in the presence of his friends.)

8. /'laqad 'badʔat ʔaʔwa:ʔu'tta:ʔira lka'bi:ra tata'laʔlaʔ/

(The lights of the large aircraft have begun to glimmer.)

9. /'jumkin libaʃʔ issa:ʔiqi:n ʔalqiada bisurʃa ka'bi:ra/

(Some drivers can drive too fast.)

10. /ʔa'ʔ a:ʃa ʔaʔʔalibu kita:bahu 'qabla ʔimtiħan/

(The student lost his book before the exam.)

• Baghdadi Arabic set of sentences is as follows:

1. /da'radʒti bimtiħa:n irija:ʔijja:t kulɪʃ qali:la/

(My grade in Maths exam was very low.)

2. /'ʔaku 'su:g bniħa:jat iʃa:raʃ/

(There is a market at the end of the street.)

3. /'laʃab ilwalad 'ʔo:ba/

(The boy played football.)

4. /'ʔɪʃtara ilwalad ʔilaqa'la:m min ʔɪldu'ka:n/

(The boy bought the pencils from the shop.)

5. /'buqa jʃi:ħ iddi:tʃ wakt ʔuʔuħa ħatta gaʃadit/

(The rooster kept shouting until I woke up.)

6. /'ma:ku ʔatjab min ilʔakla:t ilʕira:qijja/

(There is nothing tastier than Baghdadi food.)

7. /'jri:d ita:dʒir jmaʕfi bið' a:ʕta/

(The merchant wants to sell his goods.)

8. /'ʕitr ilwarid 'ma:ku 'miθla/

(The rose perfume is the best.)

9. /'ðuwa lqamar duwa lilgalub/

(Moonlight is a medicine to the heart.)

10. /'burdat iddinja wiħna mʕajfi:n/

(It became cold and we are still wearing thin clothes.)

## 5.2 Acoustic Experimentation and Analysis:

The conditions of the test consisted of the participant speaking firstly in normal environment, and then, speaking while hearing multi-talker babble (at approximately 80 dB). The data will be analyzed using computer software.

The first comparison will be conducted between two spectrograms of an Baghdadi Arabic sentence "/'buqa jʕi:h iddi:tʃ wakt ʔuðuħa ħatta gaʕadit/" (The rooster had kept shouting until I woke up.), with and without Lombard effect environments, as in Figures (1) and (2):

Figure (1) A spectrogram of /b/ in "/'buqa jʕi:h iddi:tʃ wakt ʔuðuħa ħatta gaʕadit/" (The rooster kept shouting until I woke up.) spoken in a normal conversational style without Lombard effect (Baghdadi Arabic).

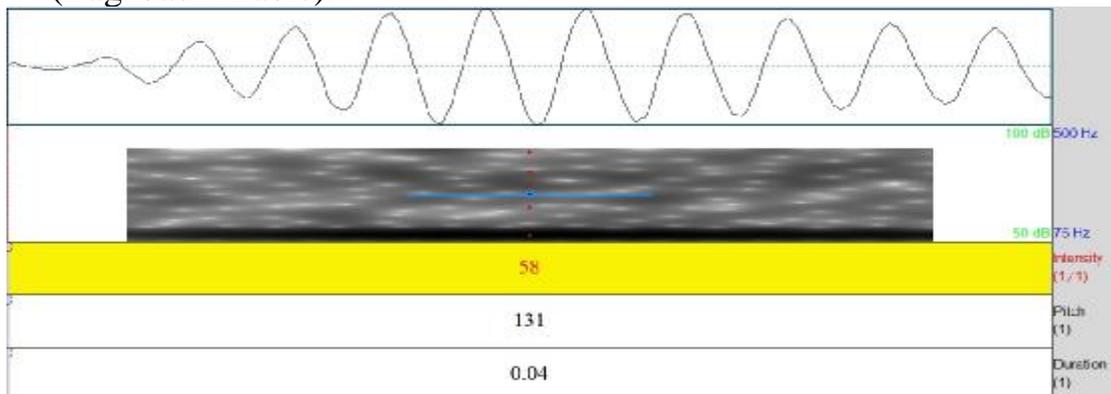
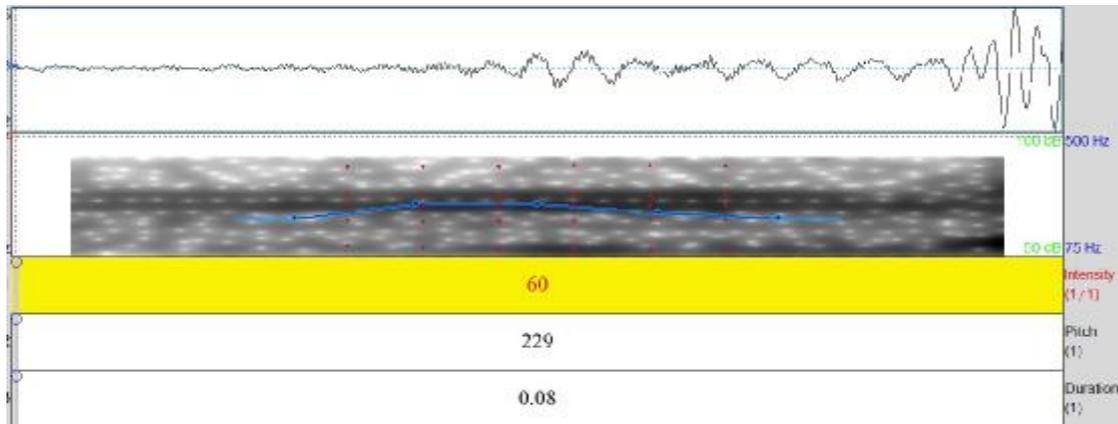


Figure (2) A spectrogram of /b/ in "/buqa jsi:h iddi:t] wakt ʔuʔuħa ħatta gaʕadit/" (The rooster kept shouting until I woke up.) spoken in a normal conversational style with Lombard effect at approximately 80 dB (Baghdadi Arabic).



The second comparison will be conducted between spectrograms of the Standard Arabic sentence "'laqad 'badʔat ʔaʔwaʔu 't̤ta:ʔira lka'bi:ra tata'laʔlaʔ'" (The lights of the large aircraft have begun to glimmer.) with and without Lombard effect environments, as in Figures (3) and (4):

Figure (3) A spectrogram of /b/ in "'laqad 'badʔat ʔaʔwa:ʔu 't̤ta:ʔira lka'bi:ra tata'laʔlaʔ/'" (The lights of the large aircraft have begun to glimmer.) spoken in a normal conversational style without Lombard effect (Standard Arabic).

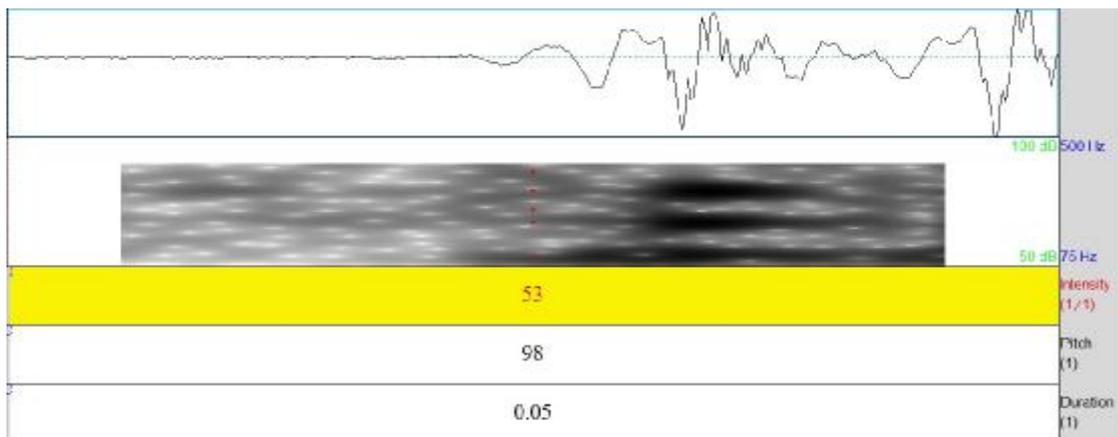
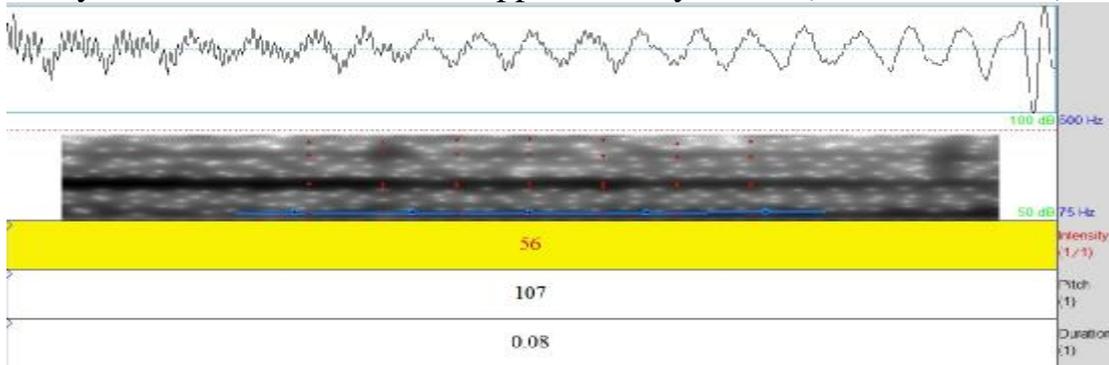


Figure (4) A spectrogram of /b/ in "'laqad 'badʔat ʔaʔwa:ʔu 't̤ta:ʔira lka'bi:ra tata'laʔlaʔ/'" (The lights of the large

aircraft have begun to glimmer.) spoken in a normal conversational style with Lombard effect at approximately 80 dB (Standard Arabic).



The third comparison will be conducted between spectrograms of an English sentence "Rugs are better to be kept dry." with and without Lombard effect environments, as in Figures (5) and (6):

Figure (5) A spectrogram of /b/ in "Rugs are better to be kept dry" spoken in a normal conversational style without Lombard effect.

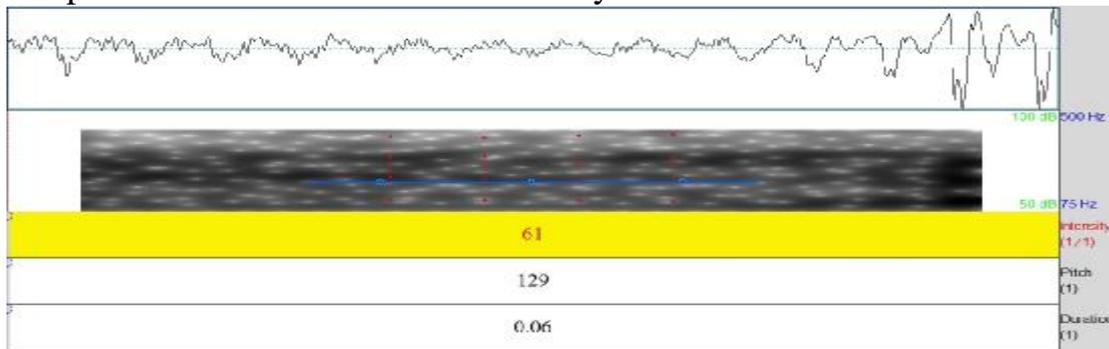
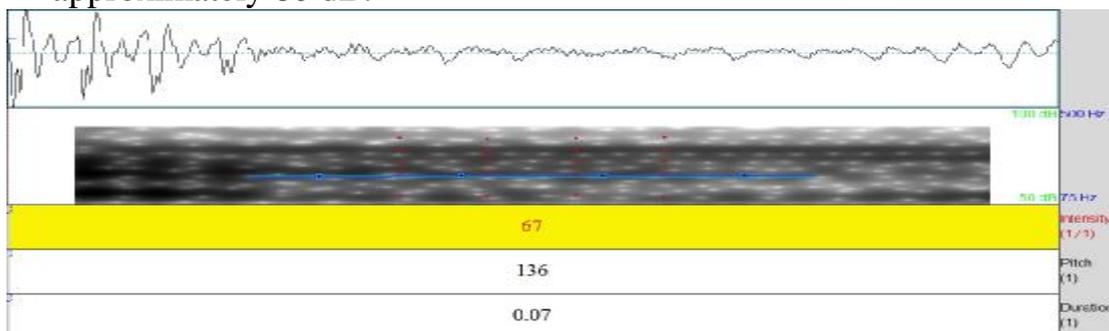


Figure (6) A spectrogram of /b/ in "Rugs are better to be kept dry" spoken in a normal conversational style with Lombard effect at approximately 80 dB.



More details of all plosives spoken in a normal conversational style without Lombard effect in English, SA, and BA are illustrated in Table (3), as follows:

English	Intensity	Pitch	Duration	Standard Arabic	Intensity	Pitch	Duration	Baghdadi Arabic	Intensity	Pitch	Duration
p	52	112	0.06	b	53	98	0.05	b	58	131	0.04
b	61	129	0.06	t	51	166	0.06	t	63	169	0.06
t	58	96	0.05	d	59	143	0.05	d	53	127	0.07
d	58	93	0.06	k	53	98	0.04	k	55	110	0.05
k	59	98	0.04	ṭ	77	205	0.04	g	60	182	0.07
g	56	192	0.06	ḡ	49	122	0.05	ṭ	64	204	0.05
				q	60	191	0.05	ḡ	53	103	0.05
				ʔ	58	140	0.04	q	56	268	0.06
								ʔ	66	221	0.04

More details of all plosives spoken in a normal conversational style with Lombard effect in English, SA, and BA are illustrated in Table (4), as follows:

English	Intensity	Pitch	Duration	Standard Arabic	Intensity	Pitch	Duration	Baghdadi Arabic	Intensity	Pitch	Duration
p	56	182	0.08	b	56	107	0.08	b	60	229	0.08
b	67	136	0.07	t	60	178	0.06	t	70	237	0.07
t	59	200	0.06	d	65	247	0.05	d	71	201	0.08
d	61	99	0.06	k	62	194	0.05	k	65	266	0.07
k	63	238	0.04	ṭ	60	236	0.06	g	70	191	0.07
g	74	262	0.07	ḡ	67	201	0.05	ṭ	61	194	0.05
				q	63	220	0.07	ḡ	63	257	0.06
				ʔ	62	243	0.05	q	61	241	0.07
								ʔ	70	224	0.05

## 6. Results and Discussion:

### 6.1 Duration

As can be noticed in Tables (3) and (4), the average durations of all words (in English, SA and BA) in Lombard speech were prolonged more than their counterparts in non-Lombard effect environments. It is worth mentioning that an increase of vowel duration in Lombard speech, and invariable duration of plosives in Lombard speech were noticed.

## **6.2 Fundamental Frequency**

There was an overall significant increase in  $F_0$  accompanying Lombard speech. The value of  $F_0$  depends on the syllable is in word-initial position or not. In addition, female speakers recorded an  $F_0$  value of 30% higher than males.

## **6.3 Pitch**

The pitch level in sentences produced with Lombard speech was 20% to 50% higher in approximately all syllables in English, SA and BA, than their counterparts without Lombard effect.

## **6.4 Auditory Remarks**

All the test informants comprehended the exact meanings of spoken sentences within Lombard speech. Several factors were noticed, e.g. loudness, stress and intensity. According to the speakers themselves, they indicated that they felt more need to boost their voice intensity whenever the noise intensity increased compared to non-noise environments. There was no misperception of plosives in both Lombard and normal speech, except in the case of one subject (in BA) with minor hearing impairment who used convergent intensity in both Lombard and normal speech.

## **6.5 Content Words**

In Lombard speech, content words were prolonged more than grammatical words especially in SA and BA due to the fact that they were spoken by native speakers of Arabic which implies a semantic dimension where the speaker assumes that syntactic structures are predictable and focus will be on content words.

## **7. Conclusions:**

From the data analysis above, the results of Lombard and normal speech in English, Standard Arabic and Baghdadi Arabic show significant changes in certain acoustic parameters although these languages are different in phonotactic and syntactic aspects. Another conclusion is that intelligibility is retained by the listeners in all tests. A huge increase of pitch level was noticed in all the language varieties investigated. Acoustic changes that occur in Lombard speech differ from person to person according to loudness level. Moreover, plosive duration is convergent in Lombard speech and non Lombard speech. Last but not least, a prolonged duration of vowels is noticed in Lombard speech. The perception of plosives (voiceless and voiced) is invariable in Lombard speech.

## **8. Recommendations:**

- It may be useful to conduct research on other types of consonants, e.g. fricatives to have a more comprehensive image of Lombard speech.
- Interdisciplinary fields can be involved in further research that includes semantic, psychological, neurological and computational aspects.

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