THE INFLUENCE OF LEXICAL STRESS ON FORMANT VALUES IN SPONTANEOUS HEBREW SPEECH

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ABSTRACT

The purpose of the present study was to examine the influence of lexical stress on formant values (mainly F1 and F2) in spontaneous Hebrew speech. Speech samples taken from a Hebrew version of the well-known Map Task dialogues were analysed, comparing stressed/unstressed vowels in word-final/non-final positions. The results showed that lexical stress has a different effect on the different vowels. Of the five vowels in the Hebrew vowel system, the vowels /a/ and /e/ were most clearly affected in a consistent manner across men and women. Similar behaviour was observed for both vowels: in word-final position the vowels were centralized similarly, regardless of stress. In non-final position, the unstressed vowels were significantly more centralized than their stressed counterparts.

Keywords: lexical stress, formants, duration, Hebrew, spontaneous speech.

1. INTRODUCTION

Lexical-stress is a phonological phenomenon that exists in many spoken languages. Correct identification and proper use of lexical stress is of great importance for maintaining effective communication [11]. Hebrew is a lexical stress language in which stress plays a distinctive role. This is evident in minimal pair cases in which pairs of words are distinguished solely on the basis of primary stress position (e.g. [ˈoxel] ‘food’ vs. [oxˈel] ‘he is eating’).

Lexical stress is one of the prosodic characteristics of Hebrew grammar, and phonological studies on the Hebrew stress system contributed over the years to its consolidation (inter alia, [1], [5], [6], [9], [17], and [20]). Briefly, Hebrew is an example of a language in which the stress rhythm is an alternation of strong-weak syllables, with major tendency of word-final, quantity-insensitive iambic. [10] found that 91.5% of the disyllabic words and 88% of the trisyllabic words in a standard Hebrew dictionary have final (ultimate) stress; [20] found that 84% of the nouns have final stress, compared to [9] who found this to be 86.8%; In a child directed speech study, [17] found that the most frequent stress pattern is the final one. It should be noted also that the assignment of stress does not seem to be affected by heaviness of syllables and there is no phonemic contrast between full and reduced vowels in strong versus weak syllables ([1], [5], [17]). Thus, the Hebrew vowel system consists of five vowels: /i, e, a, o, u/.

Over the years, many production and perception studies have been conducted on the subject of lexical stress in different languages, many of them attempting to find the acoustic correlates of stress. The three main acoustic characteristics examined in such studies are duration, intensity and fundamental frequency (f0). A fourth, often overlooked feature is related to the quality of vowels, i.e. changes in the formant values ([13], [14]). In general, all four cues can potentially be used in the production of the lexical stress, but the way these cues are weighted varies from language to language [8]. In Hebrew, it was found that duration is the most significant cue in producing stress, as compared to intensity and f0, which play a negligible role [19]. The effect on formants, however, has not yet been studied sufficiently.

A common assumption is that vowels in stressed syllables are pronounced in a more prototypical fashion, and therefore the formant values of such a pronunciation are considered as a reference form. Fry [14] was the first to examine how English vowel quality, as reflected in F1 and F2, is related to stress perception, using synthesized speech, however, he found this cue very negligible (similar findings are reported in [15] and [21]). Unstressed vowels, on the other hand, are assumed to be pronounced in a careless manner and are often omitted. This phenomenon is called "vowel reduction", and is phonetically defined as a process that causes unstressed vowels to be more central and neutral and to sound like a schwa [ə]. It should be noted that the schwa in Hebrew is not phonemic. But we will nevertheless expect to see the formants values of unstressed vowels converging and approaching the center of the vowel space. Phoneticians often refer to reduced vowels as a "reduction in vowel quality," while phonologists often describe the phenomenon of vowel reduction as a "swapping" of full vowel by the Schwa [ə] [24].

In Hebrew, Tzenker and Amir [23] found acoustic reduction in unstressed Hebrew vowels in spontaneous speech. Their results are twofold: First, that the vowel space of the unstressed vowels is smaller and more central than that of the stressed vowels; Second, that there is a displacement of the unstressed vowels in the F1 dimension into a higher position in the formant space, compared with the stressed vowels, especially for /a/. However, their study lacks phonemic balancing and therefore makes it difficult to draw general conclusions.

2. RATIONALE AND OBJECTIVES

In the current study, we examined the effect of lexical stress on the first and second formants in Hebrew speech. In addition, we wished to take into account two additional factors that can possibly affect the results: Genre: Planned/read speech vs. spontaneous speech; and Position in the word: non-final vs. word-final syllable.

Our hypotheses are:

1. In each of the vowels, *unstressed vowels* will be more central than *stressed vowels*.
2. Vowel space in *spontaneous speech* will be *more central* than the one found for read monosyllabic words [16], which is currently considered the standard Vowel space of Hebrew.
3. In each of the five vowels there will be a *difference* between the formant values of a stressed/unstressed syllable in *non-final word position* compared to a stressed/unstressed syllable in *final position*.

3. METHODS

3.1. Corpus

Most of the above-mentioned studies used planned speech stimuli rather than spontaneous speech. Moreover, all published research on Hebrew phonetic correlates of stress were carried out on planned or read speech. In the current research, our aim was to analyze spontaneous speech, albeit in a contrived setting. This is a reasonable and often used compromise between the desire for "in the wild" spontaneous speech on the one hand, and a controlled setting enabling high quality recordings on the other hand.

In this study, we used recordings from the Hebrew Map Task database [3], also called Map-Task Corpus of the Open University of Israel (MaTaCOp). The Map Task corpus was designed by [2], and is a corpus containing high-quality audio recordings designed to stimulate unscripted dialogues with a likelihood of spontaneous linguistic phenomena occurring in spoken language.

In each session two speakers sat in chairs 80 cm apart, wearing head-mounted microphones. Each speaker was recorded on a separate channel of a stereo recording. Several measures were taken to minimize background noise and ensure the quality of the recordings: Clipboards were distributed to the participants to enable them to write in a convenient manner and to minimize the noise resulting from shifting papers. Air conditioners and computers in the room were turned off; windows and doors closed; carpets were placed under the chairs to reduce movement noises; microphones were placed close to the mouth but not touching the face. The recording device was a ZOOM H4n, using a sample rate of 96,000 hz, at 24 bit sampling depth, with no compression. Of the 32 MaTaCOp dialogues, we chose 25 recordings with native Israeli Hebrew speakers, having no fluency or speech disorders. In total, we examined 23 speakers (14 women) that were born in Israel, ages from 29 to 65 years (average: 43.7, SD 9.5).

3.2. Annotation process

All vowels in words comprised of two syllables or more, that were uttered in the middle of an utterance (not as first word or last word of the utterance) were annotated. Another inclusion criteria of words was that they were *content* words: Nouns, adjectives, numbers, verbs, modifiers (e.g., "a lot", "more"), inflected verbs (e.g., [tikax] take.FUT.2sg.masc. 'take'), nouns or adjectives containing clitics ([ha-har] 'the mountain', [l-a-masait] 'to the truck'),

We excluded *function* words, auxiliary verbs (such as [tsarix] 'should', [yaxol] 'can'), words in questions, WH-question words, and loan words.

In this work, we classified the vowels into four types:

1. Stressed vowel in non-final syllable (such as /o/ in /órex/ 'length')
2. Unstressed vowel in non-final syllable (such as /i/ in /minzár/ 'monastery')
3. Stressed vowel in final syllable (such as /a/ in /minzár/ 'length')
4. Unstressed vowel in final syllable (such as /e/ in /órex/ 'length').

The rationale behind the "final – non-final" dichotomy is based on [22], who found that the degree of reduction depends on the position of the syllable in the word, albeit in English. F1 and F2 of vowels in initial position were found closer to the prototypical values as compared to vowels in final position, which underwent stronger reduction. Moreover, as mentioned earlier, the dominant Hebrew stress pattern is the ultimate (i.e. final pattern). We therefore decided to address final stress and non-final stress as two separate categories.

3.3. Vowel Database

For each speaker, the database was intended to contain two different words for each vowel in final and non-final positions, in stressed and unstressed conditions. Thus, the database was planned to consist of: 23 Speakers X 2 Words X 5 vowels X 2 Positions (final / non-final) X 2 stress conditions (stressed / unstressed) = 920 words in total.

Certain vowels are rare in Hebrew (see [18] on the frequency of phonemes in Hebrew), and in case of certain word positions even more rare. Thus, the final database contained 887 words. Table 1 presents the number of times that each stressed or unstressed vowel appears in a final and non-final positions. It shows that there were more representations of the /a/ and /e/ vowels, slightly less of the /o/ and /i/ vowels, and the least frequent is /u/ (This frequency scale is similar to the relative frequencies of vowels that were found in [18]).

Table 1: Frequency data for the different vowels

Vowel condition	/a/	/e/	/i/	/o/	/u/	Total
Stressed/non-final	50	52	39	41	9*	191
Unstressed/non-final	54	50	53	49	51	257
Stressed/final	54	47	53	48	49	251
Unstressed/final	52	50	26	44	16*	188
Total	210	199	171	182	125	887

3.4. Formant extraction

Formant extraction was performed through downsampling and applying Linear Predictive Coding (LPC) (in the same manner used by Praat [4]). This was applied to 30-50ms frames, from the centre of each vowel, judged visually to be stationary. The first two formant frequencies were identified as the frequencies of the first two conjugate pole pairs obtained from this analysis. Generally, the results of this type of analysis may vary considerably when applied automatically, depending on sampling rate and order of the LPC algorithm. Therefore, we performed a manually supervised analysis of each vowel separately using MATLAB tool that was designed for this task. It is noteworthy that none of the vowels were reduced to the point of not being amenable to analysis.

4. RESULTS

4.1. Comparing overall vowel spaces

Figure 1 and Figure 2 present the vowel spaces for women and men respectively. For reference, we also included what are considered the prototypical values for Hebrew, from [16].

Looking at figures 1 and 2 some general trends can be observed. For women, the vowel spaces found here are all more centralized than the vowel space in [16], whereas for men this is much less obvious. No overall trend for centralization of *all* unstressed vowels can be seen. However, two quite obvious and consistent trends (across gender) between stress and vowel position are found for /e/ and /a/: in both cases, stress appears to have little effect for vowels in word final position (dashed lines), but a major effect for vowels in non-final position (dotted lines). Extensive statistical analyses were carried out on this data, however in the following sections we present only the results that were consistent across gender.

Figure 1: Women's vowel spaces for all the four conditions examined here, together with the vowel space of planned speech as reported in [16].

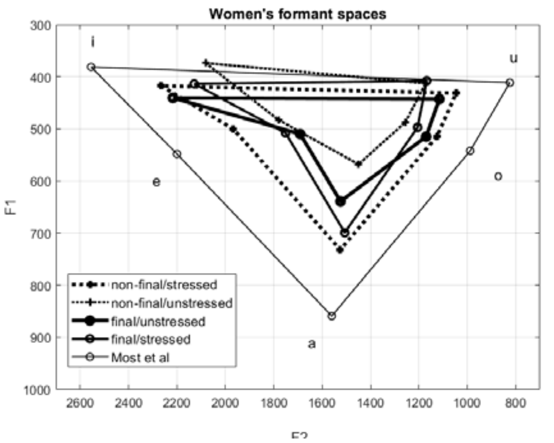
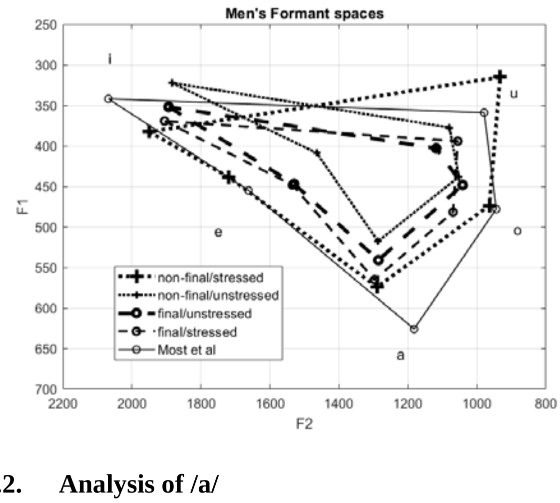


Figure 2: Men's vowel spaces for all the four conditions examined here, together with the vowel space of planned speech as reported in [16].



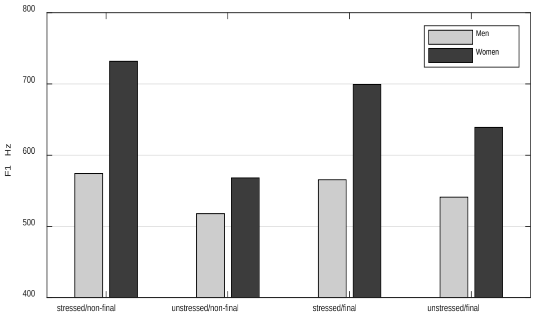
4.2. Analysis of /a/

Analysis of variance with repeated measures was performed over **F1**, for men and women separately, with Stress and Position as within-subject factors. Results were as follows:

Men: A main effect was found only for Stress (p = 0.005). No main effect was found for Position, nor was there a significant interaction. Two Further t-tests compared F1 values of stressed vs. unstressed vowels, separately for final and non-final positions, revealing a significant difference between stressed and unstressed only in the non-final position (p=0.019), with higher values for the stressed condition.

Women: A main effect was found only for Stress ($p < 0.001$). No main effect was found for Position, nor was there a significant interaction. Two Further t-tests compared F1 values of stressed vs. unstressed vowels, separately for final and non-final positions, revealing a significant difference between stressed and unstressed in both positions (p=0.001, p=0.006). Again, higher values were found in the stressed condition.

Figure 3: F1 values for /a/, for men and women



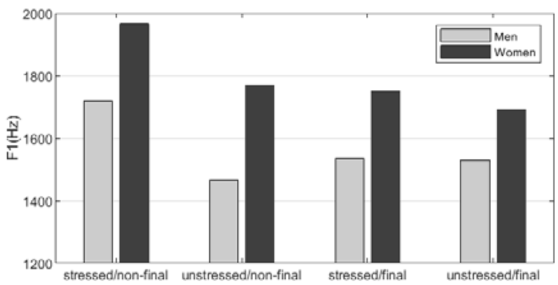
4.3 Analysis of /e/

Analysis of variance with repeated measures was performed over **F2**, for men and women separately, with Stress and Position as within-subject factors. Results were as follows:

Men: A main effect was found only for Stress (p = 0.012). Higher values in stressed vowels. A strong Stress*Position interaction (p=0.005). As above, further t-tests revealed a significant difference between stressed and unstressed conditions only in the non-final position (p=0.005).

Women: A main effect for Position (p=0.01) and a marginal effect for Stress (p=0.057). No interaction was found. Again, as significant difference between stressed and unstressed conditions was found only in the non-final position (p=0.027).

Figure 4: F2 values for /e/, for men and women



5. DISCUSSION

Regarding our three hypotheses, we did not find evidence that *all* unstressed vowels are more central than *all* stressed vowels. As for the second hypothesis, we found that only women's formant values of *all* vowels in spontaneous speech are more central than the formant values found for read monosyllabic words. The third hypothesis was that in each of the five vowels there will be a *difference* between the formant values of a stressed/unstressed syllable in *non-final word position* compared to a stressed/unstressed syllable in *final position*. Here we found difference only for two vowels – /a/ and /e/.

Indeed, the most consistent effects observed above, and supported by the statistical analysis, point to the fact that in Hebrew the first two formants of /a/ and /e/ are affected in a similar manner by lexical stress. However, the effect of stress is strongly dependent on position in the word. In the word-final position, both vowels are more centered, to the same degree, regardless of whether they are stressed or not. This is reflected in F1 for /a/, and F2 for /e/. In non-final position, however, the centralization depends strongly on stress: Stressed vowels are weakly centered, if at all, whereas non-stressed vowels are more strongly centered. Again, this is reflected in F1 for /a/ and F2 for /e/. According to [12], reduction will be expressed first in the height of the vowel (F1 values), prior to contrasts of backness or lip rounding. [12] claims that this happens because the production of low vowels is more difficult in unstressed syllables. Indeed, we see more change in F1 values in the lower vowel (/a/) than in the higher vowels. It can also be claimed that "for the sake of the vowel system" in Hebrew, only /a/ can undergo F1 reduction without losing its phonemic contrasts, while in the other Hebrew vowels phonemic contrast will be endangered. As for F2 reduction in /e/ and not in other vowels, this can be explained by the fact that when the Hebrew orthographic Schwa represents a vowel, it is always realized as [e] in Modern Hebrew speech [7].

6. CONCLUSIONS

In spontaneous Hebrew speech, lexical stress has a different effect on the different vowels. The effect on /a/ and /e/ is most consistently observable. When in word-final position, both are reduced to the same degree, regardless of lexical stress. In non-final position, reduction becomes highly dependent on stress, with stronger reduction in the unstressed case.

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