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Modern Hebrew stress

Phonology and phonetics

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Abstract

The paper provides a comprehensive description of the phonology and phonetics of Hebrew stress. The distribution of the stress patterns draws a categorial distinction between verbs and nouns, and enhances the typologically uncommon disparity between the most common pattern (final stress) and the default pattern (penultimate stress). As the acoustic studies reveal, the main cue for Hebrew stress is duration, though the duration contrast is eliminated between a phrase final unstressed syllable and the preceding stressed syllable. A second important result of the acoustic studies is that there is no evidence for secondary stress.

Keywords

Hebrew stress – default stress – acoustic cues

1 Introduction

Hebrew primary stress resides within the trisyllabic window, i.e. on one of the right-most three syllables in the word, with final stress being the most com-

mon pattern (Boložky 1982, Bat-El 1989, 1993, 2018, Graf 1999, Becker 2002, Graf and Ussishkin 2002, Cohen 2010, Pariente and Boložky 2014, Cohen and Ussishkin 2013). Secondary stress has been claimed to reside on every other syllable away from the main stress (Boložky 1982, Kadmon 1986, Bat-El 1993, Graf and Ussishkin 2002, Cohen and Ussishkin, 2013, Boložky 2015), but this claim is not acoustically supported (Becker 2002, Boložky 2015, Cohen et al. 2018).

In this paper, we provide the details of the phonology and phonetics of Hebrew stress. In the phonology section (§ 2), we attend to the distribution of stress in nouns (§ 2.1) and verbs (§ 2.2), showing that since this distribution does not comply with universal typology, the penultimate stress pattern emerges when possible (§ 2.3). In the phonetic section (§ 3), we support earlier claims that vowel duration is the major acoustic cue for primary stress (§ 3.1), and that the acoustic cues for secondary stress are, at best, weak and inconsistent (§ 3.1). Intonation is then briefly addressed with reference to its interaction with stress (§ 3.3).

2 The distribution of stress

Although final stress is dominant in both nouns and verbs, the stress pattern in these two categories differs to a certain extent, with verbs being more systematic, given their rich inflectional paradigms. Therefore, the following discussion attends to each class separately.

2.1 Nouns

The most frequent stress pattern in Hebrew is final stress, which constitutes about 75% of the noun stems in Boložky and Becker's (2006) Living Lexicon (see similar percentages in Adam and Bat-El 2008, 2009 and Segal et al. 2009). Final stress is found mostly in native nouns (e.g. *gamád* 'dwarf', *sifrijá* 'library', *melaféfón* 'cucumber'), as well as in a few loanwords (e.g. *salát* 'salad', *balón* 'balloon'); see Cohen (this volume) on stress in loanwords. Penultimate stress is found in loanwords (e.g. *avokádo* 'avocado', *πρωτέκτῆςja* 'protection'), as well as in two types of native words: (i) the segolate nouns (Bat-El 1989, 2012, Boložky 1995, Faust 2014), which are characterized by their penultimate stress in the stem and a vocalic pattern restricted to non-high vowels (e.g. *kéteḅ* 'crown', *χódef* 'month', *śáxaḅ* 'dawn'); and (ii) words with final historical gutturals (Faust 2005, Enguehard and Faust 2018), where historical /ʔ/, /ʕ/ and /h/ are usually null in Modern Hebrew (Asherov and Cohen this volume), and *ḥ* is realized as *χ* (e.g. *favúa* 'week', *tapúax* 'apple'; adjacent vowels are heterosyllabic). Antepenultimate stress is restricted mostly to loanwords (e.g. *télefon* 'phone', *śokolad*

'chocolate'), but can be found in a few names (e.g. *χάνuka* 'Hanukkah' and a few children's game-names (e.g. *mátana* 'present')). Pre-antepenultimate stress is only found in loanwords (e.g. *béjbisiteκ* 'babysitter').

The percentage of final stress is a bit higher in Fainleib's (2013) sub-corpus of the Living Lexicon, which includes native and native-like words only, characterized by 2–3 syllables (longer nouns are often borrowed) with CV and/or CVC syllables (the most common syllables in Hebrew). In this sub-corpus, consisting of 6811 noun types, 79% (n=5361) of the noun stems bear final stress. Much of the non-final stress in this sub-corpus is attributed to loanwords, which constitute 13% (n=853) of the native-like words. Out of these loanwords, only 36% (n=304) are stress-final, compared to native words where 85% (n=5057) are stress-final.

The Hebrew stress system is not sensitive to the different syllable types, and therefore syllables with codas are not heavier than syllables without codas (unlike in English and Arabic, for example), i.e. Hebrew stress is quantity-insensitive (Bolzky 1982, Bat-El 1989, Graf 1999).

(1) Hebrew stress with reference to syllable structure

Stressed syllable	Final		Penultimate		Antepenultimate	
CV	mis.pó	'fodder'	ké.lev	'dog'	té.le.fon	'phone'
	ki.tá	'class'	tí.βas	'corn'	jó.ko.lad	'chocolate'
	χa.tu.ná	'wedding'	βa.ké.vet	'train'	ββó.ko.li	'broccoli'
CVC	ful.χán	'table'	tvák.toκ	'tractor'	ám.bu.lans	'ambulance'
	ka.dúβ	'ball'	sáf.ta	'grandma'	ám.buκ.geβ	'hamburger'
	a.vi.βón	'airplane'	más.tik	'gum'	béj.ga.le	'pretzels'

The data above reflect unpredictable lexical stress, and it is thus inevitable to find minimal pairs like those in (2), where two words share syllabic structure but differ in the position of stress.

(2) Contrastive stress in nouns (L stands for a recent loanword)

Final		Penultimate		Antepenultimate
sa.pá	'couch'	sá.ba		'grandpa'
bi.βá	'capital city'	bí.βa		'beer' L

(cont.)

Final		Penultimate		Antepenultimate		
smi.χá	'blanket'	glí.da		'ice cream'		
bo.kéɤ	'cowboy'	bó.kɛɤ		'morning'		
mal.ká	'queen'	sáf.ta		'grandma'		
kaɤ.tél	'cartel' L	ʃpáχtel		'spatula' L		
mas.kít	'gift'	más.tik		'gum'		
kaɤ.tís	'ticket'	káɤ.tiv		'ice cream bar'		
klas.tɛɤ	'portrait'	plás.tɛɤ		'plaster' L		
ma.ta.ná	'present'	ba.lá.ta		'tile' L (Arabic)		
χa.fe.χá	'darkness'	ka.sé.ta		'cassette' L		
χa.go.ɤá	'belt'	pa.gó.da		'pagoda' L		
al.ma.ná	'widow fm.'	al.pá.ka		'alpaca' L		
ʃu.li.já	'apprentice'	tu.ɤí.ja		'hoe' L (Arabic)	mú.zi.ka	'music' L
		man.do.lí.na		'mandolin' L	ɤ.mó.ni.ka	'harmonica' L
		te.ɤa.kó.ta		'terracotta' L	me.tá.fo.ɤa	'metaphor' L

Another property that distinguishes between native words and loanwords in Fainleib's (2013) sub-corpus is the significance of the final segment. In native words, as shown below, C-final and V-final words behave alike with respect to their preference for final stress (83% and 91% respectively). In loanwords, however, the final segment is significant; final stress is still dominant in C-final words (57%), but there are only a few V-final words (5%) with final stress.

(3) Stress patterns in native vs. non-native words

	Native words (n=5958)		Loanwords (n=853)		
	Final	Penult.	Final	Penult.	Antepenult.
C-final	83%	17%	57%	33%	10%
V-final	91%	9%	5%	86%	9%

The data above suggest that stress in Hebrew nouns is at least partially lexically specified. This is further supported by the behavior of stress in the morphological paradigm. Nouns with an identical stress pattern in the stem may have

different stress patterns when a suffix is added (e.g. *zamák–zamáκ-ím* ‘singer(s)’ vs. *bazák–bazák-ím* ‘bazaar(s)’), and nouns with an identical stress pattern in their suffixed forms may have different stress patterns in the stems (e.g. *gamál–gmál-ím* ‘camel(s)’ vs. *kéter–ktár-ím* ‘crown(s)’).

The classification of nouns with respect to stress must be based on their behavior in the paradigm, rather than on the stress pattern in the stem (Bat-El 1989, 1993, Melčuk and Podolsky 1996, Graf 1999, Bolozky 2000). Two parameters are relevant for the classification of the nouns with regard to their stress: The stress pattern in stems (final vs. penultimate) and its mobility in suffixed forms (mobile vs. immobile). These two parameters yield four groups of nouns, as shown below with the number paradigms (singular–plural).

(4) Four types of stress paradigm

	Final in stem			Penultimate in stem				
Mobile	a.	χut	χutím	‘string’	c.	nékev	nekavím	‘hole’
		tavlín	tavliním	‘spice’		χéδεκ	χadaβím	‘room’
		melafefón	melafefoním	‘cucumber’		ǰóβεǰ	ǰovaǰím	‘root’
Immobile	b.	tut	tútím	‘strawberry’	d.	méτεκ	métvím	‘meter’
		χamsín	χamsínim	‘heat wave’		tívαs	tívαsim	‘corn’
		ipopotám	ipopotámim	‘hippopotamus’		τράκτοκ	τράκτοβim	‘tractor’

Of the four types above, those with mobile stress are the most common, as they characterize native vocabulary. Immobile stress is found mostly, but not exclusively, in loanwords (Schwarzwald 1998, Cohen this volume) and acronym words (Bat-El 1994, Zadok 2002). Becker (2003) draws the generalization that stems with mobile stress tend to be maximally disyllabic, and stems that do not comply with the disyllabic maximum bound have fixed stress (counterexample: *melafefón–melafefoním* ‘cucumber(s)’). He divides the lexicon into three strata: Stratum C with nouns of any size and any stress pattern and immobile stress; stratum B with nouns and adjectives of any size and immobile final stress; and stratum A with maximally disyllabic nouns, adjectives with mobile stress.

Antepenultimate stress, found almost only in loanwords, is hardly ever shifted to the end of the word, and is thus immobile. However, with the addition of a suffix, stress is positioned outside the trisyllabic window (e.g. *télefonim* ‘phones’), and therefore optional stress shift is often observed in suffixed forms

(e.g. *télefon-télefonim* ~ *telefonim* ‘phone(s)’, *ámbulans-ámbulansim* ~ *ambulánsim* ‘ambulance(s)’), though not always. In a few words, there is a semantic distinction (for some speakers) between the two variants (e.g. *télefonim* ‘phone (the apparatus)’ vs. *telefonim* ‘phone calls’).

Semantic contrast and variation is not limited to words with antepenultimate stress. Semantic contrast based solely on stress is also found in *ṣṣfon-í* ‘northern’—*ṣṣfón-i* ‘a person from the north of Tel-Aviv (upper class)’, both related to *ṣṣafón* ‘north’, and *klaf-ím* ‘cards’—*kláf-im* ‘card games’, both related *kláf* ‘card’ (Schwarzwald 1998). Variation in the stress pattern is also found in names (e.g. *jónatan* ~ *jonatán*, *ḡána* ~ *ḡaná*), where the normative final stress is usually associated with formal speech (Bat-El 2005), and miscellaneous words (e.g. *káma* ~ *kamá* ‘how many’, *támid* ~ *tamid* ‘always’), where the position of stress depends on register and/or the prosodic environment of the word.

Nominal suffixes, like the stems, are also classified according to the mobility of stress (Bat-El 1993). Suffixes with immobile stress, mostly borrowed, are divided into two types:

- a. The *accented suffixes* (-*ist*, -*eṣ*, and -*ái*), which just like the accented stems, preserve their stress when followed by another (non-accented) suffix; and
- b. The *preaccenting suffixes* (-*nik* and -*ḡik*), which are preceded by a stressed syllable even when followed by another (non-accented) suffixes.

(5) Immobile stress in suffixes

a. Accented

<i>komuníst</i>	‘communist’	<i>miljonéṣ</i>	‘millionaire’
<i>komunístim</i>	‘ms.pl’	<i>miljonéṣim</i>	‘ms.pl’
<i>komunístit</i>	‘fm.sg’	<i>miljonéṣit</i>	‘fm.sg’
<i>komunístijot</i>	‘fm.pl’	<i>miljonéṣijot</i>	‘fm.pl’
<i>maṣokái</i>	‘Moroccan’		
<i>maṣokáim</i>	‘ms.pl’		
<i>maṣokáit</i>	‘fm.sg’		
<i>maṣokáijot</i>	‘fm.pl’		

b. Prestressing

<i>ṣṣipúṣṣnik</i>	‘handyman’	<i>baḡúṣṣḡik</i>	‘young fellow’
<i>ṣṣipúṣṣnikim</i>	‘ms.pl’	<i>baḡúṣṣḡikim</i>	‘ms.pl’
<i>ṣṣipúṣṣnikit</i>	‘fm.sg’		
<i>ṣṣipúṣṣnikijot</i>	‘fm.pl’		

When suffixes with immobile stress are added to an accented stem (e.g. *ṣṣrák-toṣ* ‘tractor’), their accent has a deaccenting effect because it is closer to the right edge of the word. Therefore, stress resides on the accented suffix (e.g.

tvaktovíst) and the syllable preceding the preaccenting suffix (e.g. *tvaktóvnik*; a possible word), rather than on the accented stem (**tváktovíst*, **tváktovnik*)

The suffixes with mobile stress, all native, are also divided into two types:

- a. The *deaccenting suffixes* (*-on* and *-an*), which remove stress from accented stems but do not preserve stress when followed by another suffix; i.e. they are not accented, unlike the accented and deaccenting suffixes (5), which are deaccenting because of their accent.
- b. The *plain suffixes* (all other suffixes), which are oblivious to stress, thus stressed in final position when attached to unaccented stems, and unstressed when attached to accented stems or when in non-final position.

(6) Suffixes with mobile stress

a. Deaccenting (*-on*, *-an*)

tváktor 'tractor' tvaktovón 'little tractor' tvaktován 'tractor driver'
tvaktovoním 'pl.' tvaktovanít 'fm.'

b. Plain

i. Unstressed when attached to accented stems/suffixes (e.g. *-im*, *-it*)

tváktor 'tractor' tvákovím 'pl.'
tvaktovíst 'tractor driver' tvaktovístim 'pl.' tvaktovístit 'fm.'
mankál 'CEO' mankálím 'pl.' mankálit 'fm.'

ii. Stressed when attached to plain stems/suffixes (e.g. *-i*, *-ut*)

kamút 'quantity' kamutí 'quantitative' kamutiút 'quantitativeness'
sóf 'end' sofí 'final' sofijút 'finality'

In addition to *-nik* and *-fík* (5b), the suffix *-i* appearing in (truncated and non-truncated) hypocoristics is also preaccenting (Bat-El 2005), as it is always preceded by a stressed syllable regardless of the stress pattern in the base of the hypocoristic (e.g. *tíki*, *vévi*, *móvdi*, *míxáli*, *vevitáli*). The same goes for family names (e.g. *smuéli*, *mizváxi*; cf. the adjective *mizvaxí* 'eastern', with the adjectival *-i*). Hypocoristics also have the pre-preaccenting suffix *-le* (Yiddish loan), which imposes antepenultimate stress (e.g. *xánale*). The difference between these two suffixes is not limited to the position of stress (penultimate for *-i* vs. antepenultimate for *-le*), but also expands to the fate of the base's stress. The suffix *-i* has a deaccenting effect, as it removes the stress pattern of the base (e.g. *tíki* ← *tíkva*, *vévi* ← *vevitál*). The suffix *-le* is not deaccenting, and thus the stressed syllable in the base must also be stressed in the derived hypocoristics (e.g. *sivánile* ← *siván*, *tíkvale* ← *tíkva*, *nóamle* ← *nóam*).

2.2 Verbs

Compared to nouns, the stress system in the verb paradigms is regular and consistent. In bare stems, stress is usually final (5a), with the exception of a few verbs ending with a historical guttural.¹ In suffixed verbs, stress depends on the structure of the stem and the suffix. In the elsewhere cases, stress is final when the suffix is vowel-initial (5b) and penultimate when it is consonant-initial (5c). In addition, in two types of stems, stress is penultimate in all suffixed forms: in monosyllabic stems and in stems with a high vowel in the last syllable.²

(7) Three types of verbs (penultimate shaded)

			Elsewhere	Stems with V[+high]	Monosyllabic stems
			'grow'	'begin'	'sing'
a. No suffix	3.MS.SG.	PAST	gadál	itχíl	jáʔ
	2.MS.SG.	FUT.	tigdál	ta-tχíl	taʃíʔ
b. V-initial suffix	3.FM.SG.	PAST	gadl-á	itχíl-a	jáʔ-a
	2.FM.SG.	FUT.	tigdel-í	ta-tχíl-i	taʃíʔ-i
c. C-initial suffix	1.SG.	PAST	gadál-ti	itχál-ti	jáʔ-ti
	2.PL.	PAST	gadál-tem	itχál-tem	jáʔ-tem

As shown below, the majority of verbs in Bolozky's (2008) list of the 499 most frequent verbs in Hebrew belongs to the elsewhere group.

(8) Frequencies of the three types of verbs

	Elsewhere		Stems with V[+high]		Monosyllabic stems		Total
Type	385	77%	99	20%	15	3%	499
Token	256,152	78%	58385	18%	12266	4%	326,803

1 Verbs which historically had a final historical guttural (*h, ʕ, h*) are exceptional (fewer than 5%), as they bear non-final stress; e.g. *iftía* 'surprised' (< **hifíʔa*), *ivtiʔ* 'promised' (< **hiv-tíʔ*). Most of these verbs are identified on the basis of the V₁V₂ sequence, where V₂ is /a/.
 2 The high vowel lowers to /a/ in a closed syllable, as do all vowels in the stem final syllable (see

In the inflectional paradigm of the elsewhere group, 12 finite forms bear final stress and 4 bear penultimate stress. In the inflectional paradigm of the other two groups, 7 finite forms bear final stress and 9 bear penultimate stress. All in all, in the verb paradigms too, final stress is predominant, more or less to the same extent as in nouns.

The above generalizations hold for the past and future forms of verbs. The stress pattern in participles, which are traditionally presented in the verb paradigm though they may function as verbs, nouns or adjectives, follows that of native adjectives (Bat-El 2005). Thus, the past form with penultimate stress *hitχíl-a* ‘she started’ contrasts with the participle form with ultimate stress *ma-tχil-á* ‘she starts, a beginner fm.sg’. A contrast between verbs and nouns (and adjectives) is also found in monosyllabic forms, where in suffixed verbs stress is penultimate while in suffixed nouns it is final (e.g. *šáv-a* ‘she sang’—*sav-á* ‘minister fm.sg’).

2.3 *The default stress pattern*

Hebrew stress is one of the rare examples of a non-convergence between frequency and universal principles. Universally, quantity insensitive languages, which do not contrast light and heavy syllables (see (1) above) employ trochaic feet (Hayes 1995), which we interpret as penultimate stress. However, as shown in the discussion above, stress in Hebrew is predominantly final; while there are words with penultimate stress (e.g. *šéḡel* ‘foot’), most words have final stress (e.g. *govál* ‘fate’).

There are basically two different analyses of the Hebrew stress system: the mixed analysis with both iambic and trochaic feet (Graf and Ussishkin 2002), and the trochaic analysis with trochaic feet only (Becker 2002). As shown below, they differ in the foot structure they propose:

(9) Foot assignment

	Penultimate	Final
Mixed analysis—Graf and Ussishkin (2002)	[jéled]	[kadúʃ]
Trochaic analysis—Becker (2002)	[jé]led / [jéled] ‘boy’	ka[dúʃ] ‘ball’

Faust this volume). In a few forms, the high vowel is lowered to [e] for historical reasons, and stress is still penultimate across the board (e.g. *heḡénu* ‘they protected’).

The analysis proposed in Becker (2002) takes into consideration not only the position of stress but also that of the high tone. Becker argues that a high tone (marked below with ^H) appears on the stressed syllable, or the one that follows it, but not if the latter is in phrase final position (e.g. [j^{éH}]_{Ft}led_{Ph}). Crucially the high tone resides within the trochaic foot, and thus *jéled* ‘boy’ (10b) is assigned a degenerate (monosyllabic) foot in phrase final position, but a binary trochaic foot in phrase medial position.³ Note, however, that there was no acoustic evidence of this high tone shift in Cohen et al. (2018).

(10) Stress and tone

Stress pattern	Phrase final	Phrase medial	
a. Final	ba[lón ^H] _{Ph}	ba[lón σ ^H] _{Ft} ...	‘balloon’
b. Penultimate	[j ^{éH} led] _{Ph}	[jéled ^H] _{Ft} σ ...	‘boy’
c. Antepenultimate	[fóko ^H lad] _{Ph}	[fóko ^H] _{Ft} lad σ ...	‘chocolate milk’

Within the mixed analysis, Hebrew speakers have to decide between the more frequently attested iambic foot and the universally preferred trochaic foot. In the course of language acquisition, we clearly see a preference for the trochaic foot (Adam and Bat-El 2008, 2009, Ben-David and Bat-El 2016); during early stages of language production, children target and produce more trochaic than iambic words. However, soon enough, they meet the language requirement to produce more iambic than trochaic words.

This requirement is relaxed in the periphery of the lexicon (Ito and Mester 1995, 1999), where the unmarked phonological representation often emerges (Bat-El 2000, Cohen 2010, 2013). As noted, Hebrew hypocoristics (Bat-El 2005) bear penultimate stress (e.g. *smádi*, *móvdi*, *kívi*, *chézi*), regardless of the stress pattern of the base, which often varies in names). In acronym words too (Bat-El 1994, Zadok 2002), stress is often penultimate (e.g. *gálχafš* ‘shaving and polishing’), in particular in V-final forms (e.g. *tába* ‘city planning’), though there are many forms with final stress (e.g. *mankál* ‘CEO’, *bagáfš* ‘high supreme court’). The trochaic pattern is more dominant in the plural forms of acronym words; while in native plural words, stress is usually final in plural forms (e.g. *javkan-ím* ‘green grocers’; Segal et al. 2009), in acronym words, stress is predomi-

3 Pariente and Bolozky (2014) propose a trochaic system as well, but do not take tone into consideration; their footing is thus [jéled] and ka[dúš].

nantly immobile and thus plural forms bear penultimate stress (e.g. *mankál-im* ‘CEO s’) or antepenultimate stress (e.g. *jáʃvaʃs-im* ‘team meetings’).

In addition, some words have lost their final stress in favor of penultimate stress. For example, the normative *glidá–glid-ót* ‘ice-cream(s)’ is produced with penultimate immobile stress *glída–glíd-ot*, and the loanword *ʃampó* ‘shampoo’ is produced by some young speakers as *ʃámpo*.

The default trochaic foot also emerges in experimental studies. In Fainleib (2008), 12 monolingual native Hebrew speakers were asked to embed 144 nonce words in two sentence frames, one requiring the singular form and the other requiring the plural form. There were di- and trisyllabic nonce words in the experiment, half C-final and half V-final. In addition, half of the words included vocalic patterns that are frequent in Hebrew nouns (e.g. *a-a* as in *sapár* ‘hairdresser’, *a-i* as in *fatíl* ‘plant’) and half included vocalic patterns that are rare or non-existent in the language (e.g. *o-o*). The results suggest that native Hebrew speakers incline towards penultimate stress, more so in V-final words than in C-final words, and more so in words with non-existing stress pattern, where the speakers’ lexicon has a lower chance of influencing the outcome of the experiment, due to the greater dissimilarity between the nonce words and the words in the Hebrew lexicon. The results provided in (9a) are of stems with low frequency stress patterns. A similar experiment with acronym words is reported in Bat-El (2018), where 19 monolingual Hebrew speakers read 24 unfamiliar acronym words and their bases from a screen, 12 of these were C-final and 12 V-final. As shown below, in both experiments there was preference for a trochaic foot, i.e. penultimate and antepenultimate stress.

(11) Preference for trochee in experimental studies
a. Nonce words (Fainleib 2008)

	Stems			Inflected stems			
	Final	Penult.	n	Final	Penult.	Antepenult.	n
C-final	68%	32%	430	30%	60%	10%	144
V-final	17%	83%	431	32%	29%	39%	62
Total	43%	57%	861	31%	51%	18%	206

b. Acronym words (Bat-El 2017)

	Stems		
	Final	Penult.	n
C-final	94%	6%	216
V-final	17%	83%	214
Total	43%	57%	430

As suggested in Bat-El (2018), the experimental results, the trochaic stress pattern in the periphery of the lexicon (hypocoristics and acronym words), and the recent sporadic changes in the lexicon indicate an ongoing change towards the dominance of the trochaic foot (first in V-final words). If we assume a trochaic system (Becker 2002, Pariente and Bolozky 2014), the change will have to affect both the position of stress (from final to penultimate) and the foot structure (from degenerate to binary foot); i.e. from [jam[pó]_{Ft} to [jámpo]_{Ft}. However, if we assume the mixed system (Graf and Ussishkin 2002), prominence shift will affect words with final stress and will apply within a foot; i.e. from [jampó]_{Ft} to [jámpo]_{Ft}. That is, the change is relatively smaller under the mixed system—a stress shift within a foot.

3 The phonetics of stress

To complement the discussion on the phonology of stress, this section describes the acoustic correlates of word level primary stress (§ 3.1), showing that vowel duration is the major acoustic cue for stress in Hebrew. We also attend to the weak and inconsistent acoustic correlates of secondary stress (§ 3.2), which has been claimed to be assigned to every other syllable (alternating pattern) away from the primary stress. We conclude this section with the interaction between the acoustic correlates of word-level stress and phrasal intonation (§ 3.3). In the appendix, we provide F_0 contours for disyllabic words with final (Figure A1) and penultimate (Figure A2) stress, and a quadrisyllabic word with penultimate stress (Figure A3).

3.1 Primary stress

Stress languages use one or more of the following three acoustic correlates: duration, loudness and pitch (Cutler 2005, Hayes 1995). In Hebrew, duration

is the principle acoustic cue for stress (Most 1999, Maymon 2001, Becker 2002, Amir et al. 2015), with intensity and F_0 (pitch) playing a minor role (Silber-Varod et al. 2016, Cohen et al. 2018).⁴

In Silber-Varod et al. (2016), who studied minimal pairs of disyllabic words (e.g. *kótev* ‘pole’—*kotév* ‘write’), vowel duration was found to be the dominant acoustic cue for word-level stress position in spoken Hebrew. In addition, intensity and F_0 both played a minor role in indicating stress, with intensity playing a more prominent role than F_0 . A regression analysis showed that these three cues explained 80% of the variance, with duration contributing 77% and intensity and F_0 contributing 1.5% each.

The data below, drawn from Silber-Varod et al. (2016), provide the mean overall difference of the three acoustic cues (10a–c).

(12) Absolute difference of mean values of the three acoustic cues for Hebrew stress

Difference between stressed and unstressed vowels		
	Penultimate stress pattern	Final stress pattern
a. Vowel duration (ms):	26	29
b. Vowel intensity (dB):	1.2	3.1
c. Vowel F_0 (Hz)	9 (men) 18 (women)	16 (men) 21 (women)

The three acoustic cues are also shown to interact differently in the two stress positions—final vs. penultimate stress. All t-test comparisons of the absolute differences of mean values (Table 10) between the two adjacent vowels in the same word showed that the difference between these vowels in penultimate patterns are significantly **smaller** than the difference between these vowels in final patterns ($p < 0.001$). Moreover, Silber-Varod et al. (2016) found that both vowels in the penultimate pattern have significantly higher mean F_0 than their final pattern counterparts. Among the stressed vowels, the final stressed vowel is realized with the highest intensity rates (14.8dB vs. 14.3dB), while the penultimate stressed vowel is realized with highest durational rates (99ms vs. 98ms). Among the unstressed vowels, the penultimate unstressed vowel is realized

4 See, however, Enoch and Kaplan (1969), who claim that the stressed and unstressed syllables contrast in F_0 , while syllable duration and intensity are marginal.

with the highest F_0 rates, while the unstressed final vowel is realized with the lowest rates of all three parameters.

The acoustic findings only partially correlate with the strength hierarchy provided in Ben-David and Bat-El (2017), where children acquiring Hebrew (and Arabic) were evaluated for their segmental faithfulness. While in both studies, the final stressed syllable is the strongest one and the non-final unstressed syllable is the weakest, the two differ with respect to the other two positions: In Ben-David and Bat-El, the children’s productions were more faithful in final unstressed syllables than in non-final stressed syllables, i.e. the final syllable is always more faithful regardless of stress position. This is based on children’s faithfulness, and correlates with the F_0 measures provided in Silber-Varod et al. (2016).

(13) F_0 values (Silber-Varod et al. 2016)

		Penultimate stress		Final stress	
		Stressed	Unstressed	Unstressed	Stressed
a. Men	Mean (Hz)	133	142	118	136
	STD (Hz)	13	16	10	12
b. Women	Mean (Hz)	212	228	193	214
	STD (Hz)	23	27	21	24

Cohen et al. (2018) support earlier claims that vowel duration is the sole reliable cue for primary stress in Hebrew. As for the other cues, they found that the differences in intensity between the stressed and unstressed vowels are perceptually small, which may suggest, as in Silber-Varod et al. (2016), that intensity is a supporting cue for primary stress. F_0 , however, is inconsistent, and thus claimed to be irrelevant to primary stress. While the results of intensity and F_0 are not reliable, all studies agree that vowel duration is the major cue for primary stress in polysyllabic words in Hebrew.

3.2 Secondary stress

Previous phonological studies suggest that secondary stress in Hebrew is assigned to every other syllable from the primary stressed syllable (Bolozky 1982, Kadmon 1986, Bat-El 1993, Graf and Ussishkin 2002, Cohen and Ussishkin 2013, Bolozky 2015). However, it was also claimed that secondary stress has no acoustic manifestation (Becker 2002, Bolozky 2015).

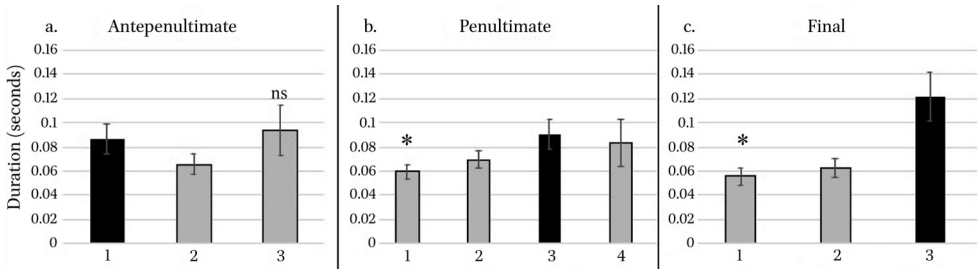


FIGURE 1 Average vowel duration (in ms) and standard deviation in the three stress patterns

A recent acoustic study reported in Cohen et al. (2018) found inconsistent and sporadic evidence for secondary stress, which supports the claim that secondary stress in Hebrew is not acoustically realized. The study's stimuli consisted of 27 target words with 3–4 syllables embedded in identical carrier sentences, with three different stress patterns—final, penultimate, antepenultimate (e.g. *pánama* 'Panama', *makaróni* 'macaroni', *mataná* 'gift').

Like the study on primary stress reported in § 3.1, Cohen et al. (2018) examined the three acoustic cues for stress—vowel duration, vowel F_0 , and vowel intensity. The results are recapitulated below, where the black bars represent the vowels in stressed syllables, and statistical significance is marked on the bars representing the vowels that are expected to bear secondary stress, i.e. the vowels positioned one syllable away from the main stress.

An indication of secondary stress should be manifested by a significant difference between secondary stressed syllables and unstressed syllables, and if such a difference exists, we expect it to appear in vowel duration, which was found to be the cue for primary stress in Hebrew (§ 3.1).

As argued in Cohen et al. (2018), vowel duration (Figure 1) provides a straightforward indication for the absence of acoustic cues for secondary stress. The strongest evidence comes from the lack of significant differences in vowel duration between bars 1 and 2 in the final (Figure 1c) and penultimate (Figure 1b) stress pattern; as noted above, we would expect a significant difference had there been secondary stress. The significant difference ($p < .01$) between bars 2 and 3 in the antepenultimate stress pattern (Figure 1a), which could be interpreted as secondary stress, is attributed to vowel lengthening in word final position. Not only is vowel lengthening in word final syllables a common phenomenon in languages (Hofhuis et al. 1995, Turk and Shattuck-Hufnagel 2007), it also appears in the penultimate stress pattern (Figure 1b), where there is no significant difference in vowel duration between bars 3 and 4, i.e. the stressed vowels and the adjacent final vowels. Here again, one vowel

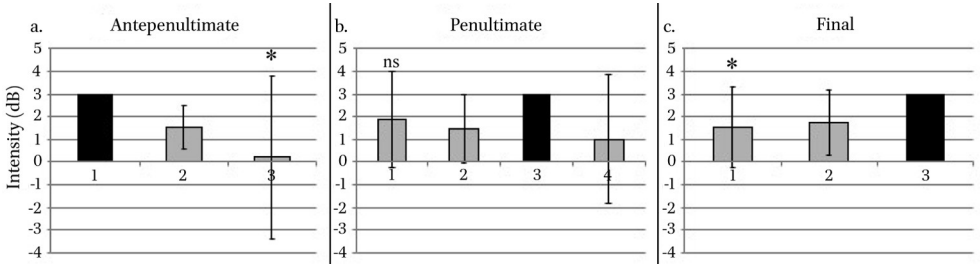


FIGURE 2 Average intensity (in dB) of the vowels and the standard deviation in the three stress patterns

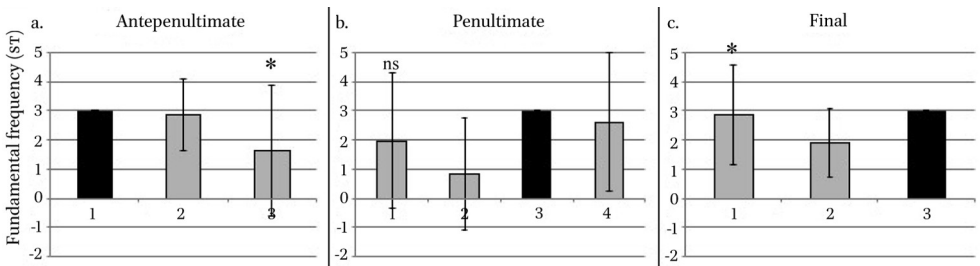


FIGURE 3 Average F_0 (in semitones) of the vowels and standard deviation in the three stress patterns

is long due to its metrical status (stressed) and the other due to its prosodic position (final).

The two other cues, intensity (Figure 2) and F_0 (Figure 3), provide inconsistent results, with significant differences in the antepenultimate and final stress patterns, as expected in the absence of cues for secondary stress, but insignificant differences in the penultimate stress pattern (Figure 2b and Figure 3b).

3.3 The interaction of stress with intonation

In their study of the interaction between F_0 and duration in a corpus of weather broadcasts, Silber-Varod and Kessous (2008) show that duration is not a consistent cue and is affected by the position of the word. At the intonation unit boundaries (sentence final position), stressed syllables in final stress pattern are longer than the preceding unstressed syllables, but stressed syllables in penultimate pattern are not always longer than the following unstressed syllable.

As for the pitch contour (F_0), the study found that in 69% of the words with penultimate stress, F_0 was higher in the final unstressed syllable than in the penultimate stressed syllable (similarly to Silber-Varod et al. 2016), and in only

8% of the cases was the F_0 higher in the penultimate stressed (the rest are combinations of other pitch relations). However, Silber-Varod and Kessous' (2008) research was conducted on a specific corpus of weather forecast broadcasts of three female speakers, and therefore the effect of utterance location on the acoustic realization of lexical stress is still open to a comprehensive and large-scale research.

Berkovitz (1994) conducted a study on the durational parameter and the interaction between sentence-final position and lexical stress. The study focused on the distribution of the durational effect across syllables in three phonological environments: utterance-final position, verb gapping, and contrastive stress. Penultimate-stressed and final-stressed disyllabic words were read in sentence-final vs. non-final positions, and in contrastive focus vs. broad focus constructions. Contrastive focus showed a smaller effect than final lengthening, consistent with the claim that other acoustic parameters are more prominently involved in this process. Utterance-final lengthening principally affected the final syllable regardless of word stress, whereas contrastive focus primarily lengthened the stressed syllable. The pattern of progressively greater lengthening within the utterance-final syllable, previously found for stressed syllables, applied to unstressed syllables as well. The finding that target syllables in sentence-final position are characterized by progressive lengthening, unlike those in contrastive focus, supports the suggestion that utterance-final lengthening is a reflection of deceleration at the end of motor activity. However, Berkovitz' (1994) corpus consists of only seven female participants in six pairs of sentences (sentence-final and non-final positions), with disyllabic proper nouns as the target words (e.g. *ziva nas?a letijul im fmulik* 'Ziva took a trip with Shmulik'). Moreover, the recordings were carried out after a practice session consisting of a silent reading of the sentences preceding the actual reading of the sentence. Finally, in several cases, the vowel duration measurements in Berkovitz (1994) included the bursts and aspirations of the onset stops, and the penultimate versus final target words did not consist of minimal pairs (thus, the comparison is between non-identical syllables).

Silber-Varod and Amir (2017) found that the contrast of the durational parameter of lexical stress is kept in utterance final lengthening (unlike Silber-Varod and Kessous 2008). Although final lengthening does not affect the relative length of the stressed vowels, it lengthens the final vowels more than the previous vowels, regardless of stress assignment.

4 Summary

To summarize the findings reported in this paper, we wish to emphasize the unique distribution of stress in Hebrew. First, stress in Hebrew is, in many ways, category-specific; there are more stress patterns in nouns than in verbs and the system is much less regular in nouns than in verbs. What adds to the uniqueness of Hebrew stress is that the more common final stress is not the default stress revealed in experimental studies.

The acoustic studies reported here reveal that duration is the primary cue of stress and that there is no evidence for secondary stress in Hebrew.

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Appendix

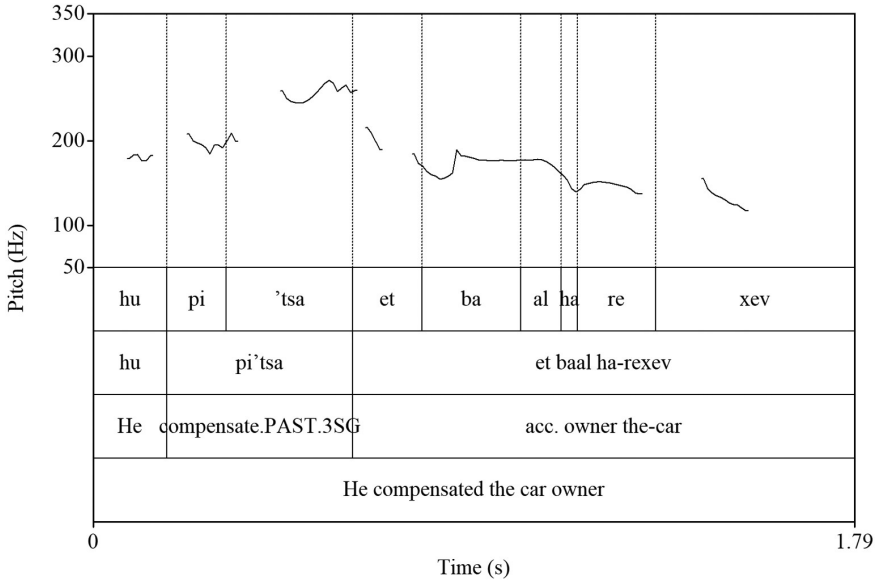


FIGURE A1 Final stress—example of target word [pifsa] 'to compensate' within a carrier sentence

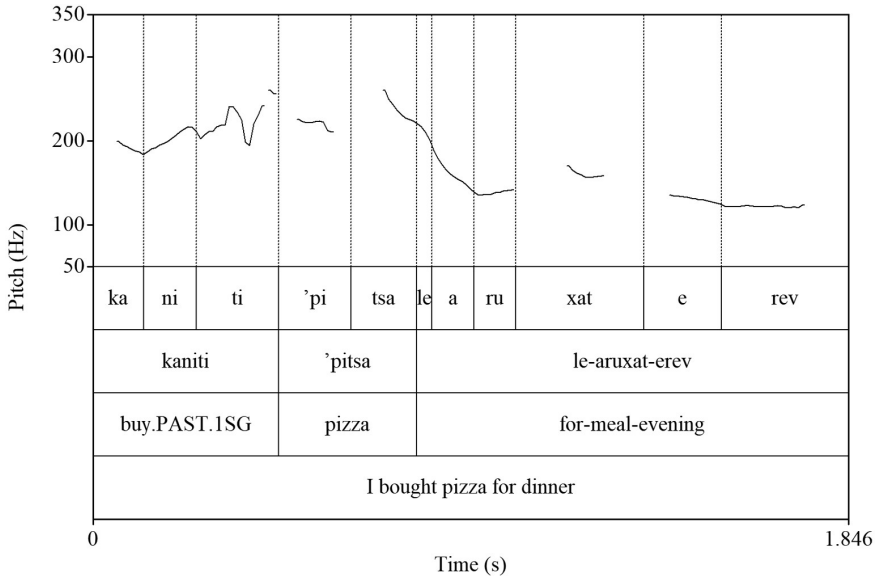


FIGURE A2 Penultimate stress—example of target word [pifsa] 'pizza' within a carrier sentence

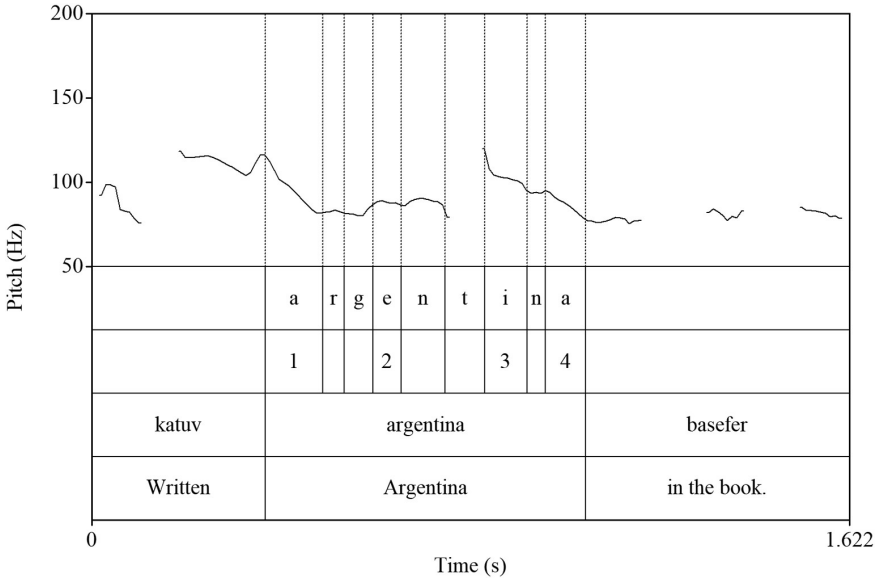


FIGURE A3 Example of target word [aɾɣɛntína] ‘Argentina’ in the carrier sentence. Vowels are marked 1–4