



BRILL

BRILL'S JOURNAL OF AFROASIATIC LANGUAGES
AND LINGUISTICS 11 (2019) 3–27

BAALL

brill.com/aall

A phonetic description of Modern Hebrew consonants and vowels

Daniel Asherov

MIT

asherov@mit.edu

Evan-Gary Cohen

Tel-Aviv University

evan@tauex.tau.ac.il

Abstract

In this paper, we provide a detailed description of the phonetic inventory of Modern Hebrew. We systematically review the phonetic contrasts that distinguish among consonants and vowels, and highlight cases of inter-speaker variation. The contrasts are illustrated with data from an ultrasound tongue imaging study of a native speaker of Modern Hebrew. We provide tongue shape comparisons based on the ultrasound recordings, as well as present acoustic data in form of spectrograms and amplitudes. We also occasionally provide quantitative data from previous studies.

Keywords

Modern Hebrew – phonetic inventory – consonants – vowels – ultrasound

1 Introduction

The goal of this paper is to provide an overview of the phonetic realization of consonants and vowels in Modern Hebrew (henceforth: Hebrew), as spoken in present-day Israel.¹ We illustrate contrasts with acoustic and articulatory data

¹ This paper focuses on the phonetic realization of Hebrew segments. Segmental phonol-

from ultrasound tongue imaging of productions by a native Hebrew speaker. We also provide quantitative data from previous experimental studies, when such data are available.

Researchers often distinguish between two varieties of Modern Hebrew pronunciation, which we refer to as the *Common Israeli* pronunciation and the *Mizrahi Israeli* pronunciation.² The varieties most notably differ in their consonantal inventories: the phonetic inventory of Mizrahi Israeli includes pharyngeals, *ħ* and *ʕ*, while that of Common Israeli does not. In addition, some speakers of the Mizrahi Israeli variety realize the rhotic as an alveolar flap, and not as the more common uvular approximant. For descriptions of the Mizrahi Israeli pronunciation, as well as inter- and intra-speaker variation in its properties, we refer the reader to Blanc (1968), Devens (1978), Schwarzwald (1981), Laufer & Baer (1988), and Gafter (2014, this volume). The descriptions in the present paper are based on productions by speakers of the Common Israeli variety.

We start by describing the process of data collection (§ 2) for the acoustic and articulatory illustrations given in this paper. In § 3 and § 4 we describe the phonetic contrasts among consonants and among vowels, respectively. We conclude in § 5.

2 Data

In the following two sections, we provide illustrations with acoustic and articulatory data from ultrasound tongue imaging (UTI) recordings of a single native speaker of Hebrew (with non-native L2 English).³ The informant is a 27-year-

ogy is discussed in detail in several other papers in this volume, including voicing assimilation (Mizrahi this volume), stop-fricative alternation (Albert this volume), consonant co-occurrence restrictions (Yevechychahu this volume), guttural morphophonology (Faust this volume-a), vowel alternations (Faust this volume-b), and loanword phonology (Cohen this volume). An in-depth investigation of the Hebrew rhotic is offered by Cohen et al. (this volume). An overview of Hebrew segmental phonology is available in Boložky (1978, 1997).

2 The two varieties have been given numerous names in the literature, many of which refer to dialect prevalence or ethnic association. The *Common Israeli* pronunciation corresponds to Blanc's (1968) *General Israeli Hebrew*, Yaeger-Dror's (1988) *Koine* and Laufer's (1990) *Non-Oriental Hebrew*. The *Mizrahi Israeli* pronunciation is sometimes referred to as *Oriental Hebrew* (e.g. Laufer 1990). To our knowledge, no study has reliably quantified the relative number of speakers that identify themselves with each of the pronunciation varieties, and in particular, the relative number of speakers producing *ħ* and *ʕ*.

3 We thank James Scobbie and the Clinical Audiology, Speech and Language Research Centre (CASL) at Queen Margaret University in Edinburgh for their help with collecting these data.

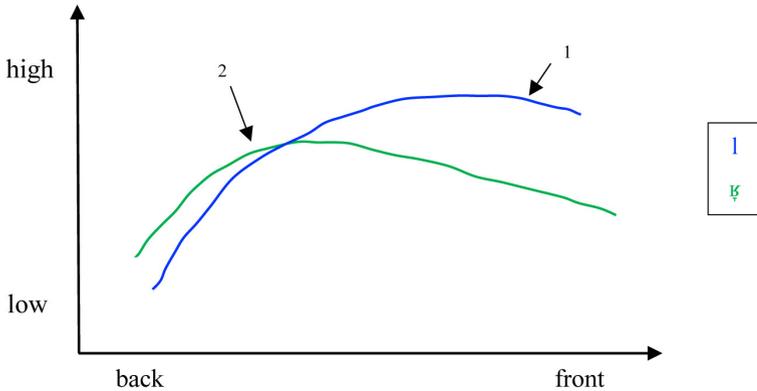


FIGURE 1 Tongue shapes in /l/, /ʁ/

old female with no training in linguistics or speech sciences at the time of the elicitation.

The informant's task was to produce words in isolation, presented orthographically in Hebrew, including vowel signs (transcriptions are provided in Appendix I). All words were disyllabic with final stress, with or without an initial onset and with or without a final coda, i.e. $(C_1)V_1C_2\hat{V}_2(C_3)$. Each of the (non-glottal) 21 Hebrew consonants was produced in C_2 , i.e. intervocalically at the onset of a stressed syllable. In order to eliminate effects of coarticulation when comparing consonants, both vowels (V_1 and V_2) were *a*, and any consonants in C_1 or C_3 were either glottal or labial, except where the target consonant was labial, in which case they were non-labial. We used real Hebrew words if possible, and nonce words otherwise. In order to disambiguate among homographs, and in particular to facilitate the detection of stress, the words were written in the context of 2–6-word phrases, which were not produced. Only the target word was produced.

Imaging data were captured in mid-sagittal view using the EchoB ultrasound system with a 20 mm 2–4 MHz probe, and with a frame rate of 60.3 frames per second. The probe was mounted on an Ultrasound Stabilization Headset (by Articulate Instruments). Field of view was set to 104 degrees, and depth was set to 75 mm. The auditory data were simultaneously recorded. The software used for data collection was Articulate Assistant Advanced (AAA).

Tongue shape plots, such as Figure 1, show the shape of the tongue surface at the point of maximal constriction. Arrows are used to indicate active articulators: arrow (1) shows the tongue blade in /l/ (tongue tip is normally not clearly visible in UTI), and arrow (2) indicates the tongue back in /ʁ/. The plots were prepared by rotating the raw frames by 15°, manually marking the upper surface of the tongue at the top border of the white line in each image, and superim-

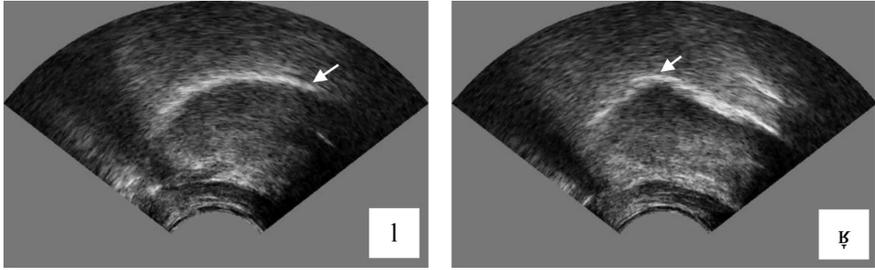


FIGURE 2 UTI frames of *l*, *ʕ* at maximal constriction. The white arrows indicate active articulators: the tongue blade in the frame on the left; the tongue back in the frame on the right.

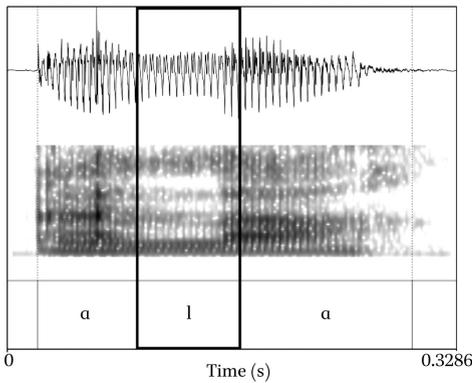


FIGURE 3 Amplitude and spectrogram of *l*.
Spectrogram range: 0–5,000 Hz

posing the tongue shapes onto one another. The plots are faithful to the relative position of the tongue surface in different segments, since all productions were collected in one session, with the same speaker, and with probe stabilization (see above). The raw frames corresponding to the consonants in Figure 1 are provided in Figure 2. All other raw frames used for plotting tongue shapes in this paper are provided in Appendix II.

Auditory recordings were analyzed with Praat (Boersma & Weenink, 2016). Spectrograms of segments include the entire word in which they were pronounced, and the segment of interest is marked with a thick frame. For example, Figure 3 shows the consonant *l* in its recorded context *alá* ‘he ascended’. We indicate the frequency range of the spectrograms below each figure.

TABLE 1 Consonant inventory

	Labial		Coronal			Dorsal		Glottal
	Bilabial	Labio-dental	Alveolar/dental	Post-alveolar	Palatal	Velar	Uvular	Glottal
plosives	p b		t d			k g		ʔ ²
affricates			ʔs	tʃ ¹ dʒ ¹				
fricatives		f v	s z	ʃ ʒ ¹			χ	h ²
nasals	m		n					
lateral approximants			l					
central approximants					j	w ^{1,3}	ʕ	

1 loan consonant; 2 phonological status is controversial (see § 3.1.4); 3 labio-velar

3 Consonants

The inventory of contrasting consonants in Hebrew is given in Table 1. The table includes loan consonants (marked 1) and glottals (2). Glottals are frequently omitted, especially in rapid speech (see § 3.1.4).

Pharyngeal consonants, not included in Table 1, do not form a part of the inventory of the vast majority of native Hebrew speakers.⁴ However, some speakers of the *Mizrahi Israeli* variety do preserve the distinction between χ and ħ (*kaχ* ‘so’ vs. *kaħ* ‘take!’) and between ʔ and ʕ (*ʔoʕ* ‘skin’ vs. *ʔoʕ* ‘light’) from older stages of Hebrew. We refer the reader to Devens (1978) and Laufer & Baer (1988) for phonetic investigations of Hebrew pharyngeals, and to Gafter (2014, this volume) for a study of the sociolinguistic aspects of Hebrew pharyngeal production. The phonological status of the historical pharyngeals in the underlying representations of speakers without surface pharyngeals is a matter of controversy; see Bolozky (1978), Matras & Schiff (2005), Faust (2005, this volume-a), Laks et al. (2016), Bassel & Berrebi (2016), and Enguehard & Faust (2018).

4 Similarly, we do not include in Table 1 the alveolar tap/trill (*r* / *r*) realization of the Hebrew rhotic (Blanc 1968, Devens 1978, Schwarzwald 1981), which is produced as *ʀ* by most native speakers. This alveolar variant exists among some older speakers, but is very uncommon among younger speakers.

Consonant duration is not contrastive in Hebrew, i.e. singleton consonants do not contrast with geminates. Adjacent identical consonants across morpheme boundaries are optionally repaired by epenthesis (e.g. *saḡat+ti* → *saḡáteti* ‘I scratched’) or deletion (*baḡan+nu* → *baḡánu* ‘we examined’).

This section is divided into three sub-sections, corresponding with the three broad dimensions on which the consonants are distinguished: we describe the place of articulation of each of the consonants in § 3.1, their manner of articulation in § 3.2, and the realization of the voicing contrast in § 3.3.

3.1 *Place of articulation*

We define the place of articulation by the pairing of an active and a passive articulator, where the active articulator is moved towards the passive articulator to create a constriction. In this section, the consonants are grouped by their active articulator: lips (labials), tongue tip, blade and body (coronals), tongue back (dorsals), and glottis (glottals). The corresponding passive articulators are then specified next to each consonant class. We occasionally refer to the manner of articulation, which is described in detail in § 3.2.

3.1.1 Labials

Hebrew has five labial consonants: *p*, *b*, *f*, *v*, *w*. The two plosives *p* and *b* are **bilabial**—the lips serve both as the active and the passive articulators. The two fricatives *f* and *v* are **labio-dental**—the active articulator, the lower lip, creates a constriction with the passive articulator, the upper teeth. The approximant *w* is labio-velar: it is produced by creating a bilabial and a velar constriction simultaneously.

3.1.2 Coronals

Alveolar consonants are produced with the tongue tip or blade creating a constriction at the alveolar ridge. There are six alveolars in Hebrew: *t d s z n l*. These consonants are optionally produced as dentals, with the tongue blade reaching the back of the upper teeth. A palatograph study by Devens (1983) also found that some speakers produce inter-dental variants of these consonants, with the tongue tip or blade creating a constriction below the upper teeth. These variants are usually restricted to consonants preceding or following *i*, *e* or *a*, and are blocked when adjacent to *u* or *o*.

Hebrew has four **post-alveolar** consonants, produced with the tongue blade creating a constriction in the post-alveolar region of the hard palate. Among them, only *ʃ* is a native consonant (e.g. *ʃakét* ‘quiet’), while the other three, *ʒ*, *ʒ̥*, and *ʒ̥̃*, appear only in loanwords (e.g. *ʒakét* ‘jacket’, *ʒ̥ʃips* ‘chips’, *ʒ̥̃zins* ‘jeans’).⁵

⁵ *ʒ* also appears allophonically when *ʃ* undergoes voicing; see § 3.3.

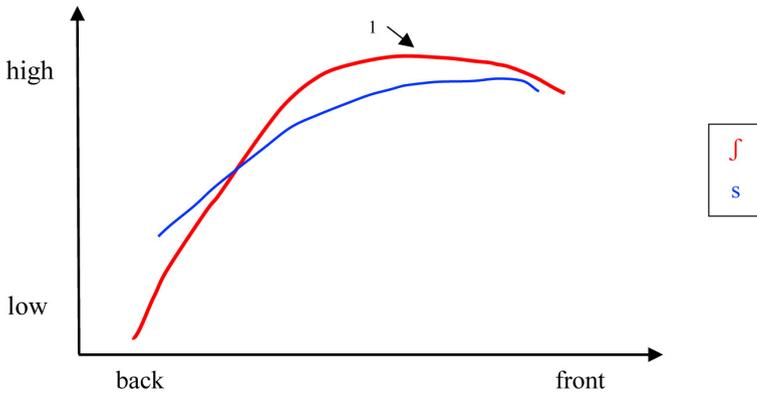


FIGURE 4 Tongue shape in anterior and non-anterior sibilants *s, f*. Tongue surface is rotated 15° from raw frames (see Appendix II).

All four post-alveolar consonants are typically produced with lip rounding, thus increasing the perceptual distance between alveolars and post-alveolars (Boersma 1998).

Figure 4 shows the tongue surface shapes of *s* and *f* produced by our informant (see method in §2) during maximal constriction with the tongue blade (the tongue tip is not clearly visible in ultrasound recordings). The raised tongue body of *f* (1) compared to *s* shows that it is produced by our informant as laminal and post-alveolar, excluding other non-anterior places of articulation, such as retroflex.

The **tongue body** is the primary active articulator only in the palatal central approximant *j*.

3.1.3 Dorsals

There are five consonants produced with the tongue back: *k g χ ʁ w*. Previous descriptions of the dorsal consonants are fairly consistent in describing the two plosives *k* and *g* as velar, and the approximants *ʁ* and *w* as uvular and labio-velar, respectively. However, the voiceless fricative is sometimes reported to be a velar *x* (Chayen 1972, Cohen 2009), and sometimes a uvular *χ* (e.g. Laufer 1990, 2008, Bolozky 1997). Kreitman & Bolozky (2007) conducted a single-speaker ultrasound tongue imaging study to test the hypothesis that *χ* and *ʁ* have the same place of articulation. They showed that, indeed, *χ* and *ʁ* have the same place of articulation, uvular, and they are both produced further back than *k*. Figure 5 shows that the production of *χ* by our speaker follows the same pattern. Both *χ* and *ʁ* are further back than *k* and *g*.

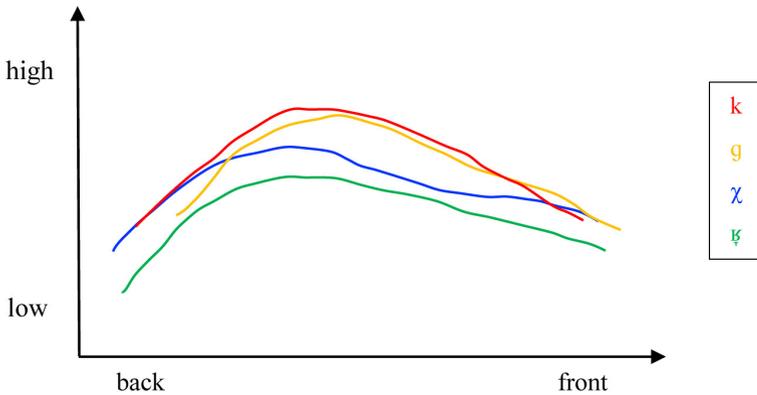


FIGURE 5 Tongue shapes in velar and uvular consonants *k*, *g*, *χ*, *ξ*. Tongue surface is rotated 15° from raw frames (see Appendix II).

3.1.4 Glottals

The two glottal consonants *ʔ* and *h* are produced by creating a constriction in the glottis. The status of *ʔ* and *h* as contrastive categories in Hebrew is controversial. The glottal stop *ʔ* alternates with *∅* (no consonant), and, in fact, its occurrences can be analyzed as cases of epenthesis as a repair of onsetless syllables (e.g. *teená* ~ *teʔená* ‘fig’, *beéξ* ~ *beʔéξ* ‘a well’).⁶ For most speakers, its realization is never obligatory, neither in careful nor in rapid speech.

Unlike *ʔ*, the glottal fricative *h* is more likely to be produced in careful speech, though some speakers optionally omit it. In rapid speech, *h* is typically deleted, or can optionally be realized as *ʔ* (Bolozky 1978). According to Matras & Schiff (2005), in cases of two occurrences of *h* in adjacent syllables, one of them is likely to be retained. See Laufer (1991) for data from fiberscope recordings of glottal fricatives.

3.2 Manner of articulation

Hebrew consonants differ with respect to the **degrees of closure** (stops, fricatives, approximants), the **laterality** of constrictions (central vs. lateral),⁷ **nasality** (oral vs. nasal),⁸ and the **articulatory activity** during offset (plosives vs. affricates).

6 This is also true for instances of *ʔ* that correspond to a historical pharyngeal *ħ*. Arguably, the historical consonants have undergone a phonological merger in Modern Hebrew. Regardless of their phonological status, both historical *ʔ* and *ħ* surface variably as *ʔ* ~ *∅* in Modern Hebrew.

7 Consonants are central unless stated otherwise. Only the consonant *l* is lateral.

8 Consonants are oral unless stated otherwise. Only the consonants *m* and *n* are nasal.

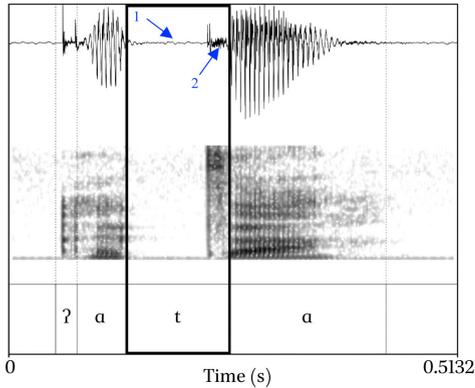


FIGURE 6 Amplitude and spectrogram of *t*.
Spectrogram range:
0–5,000 Hz

In this section, the consonants are divided into three groups according to their degrees of closure. **Stop** consonants are characterized by the complete lack of airflow through the oral tract at some point in their articulation. **Fricative** consonants are characterized by continuous airflow through the oral tract throughout their articulation with varying degrees of frication and turbulent airflow, whereas **approximant** consonants are characterized by continuous airflow through the oral tract with no significant frication or turbulence.

3.2.1 Stops

There are three types of stop consonants in Hebrew, differing in release types and nasality: plosives, affricates and nasals.

Hebrew has seven **plosives**: *p b t d k g ʔ*. The glottal stop *ʔ* has questionable phonemic status and will not be discussed in this section (see § 3.1.4 above and Faust this volume-a on gutturals). The remaining six plosives are all stop consonants with no airflow through the nasal passage and a rapid offset with very brief frication. They differ in places of articulation (bilabial *p b*, alveolar *t d*, velar *k g*), with each place having a voiced-voiceless contrast.

Figure 6 is an acoustic representation of the voiceless plosive *t*, displaying the typical properties of voiceless plosives in Hebrew. Note the complete lack of airflow during the closure (1), with a rapid offset (2) at the right edge of the consonant's waveform.

As opposed to plosives, **affricates** are stop consonants with a prolonged period of frication during their offset. There are three affricates in Hebrew: *ʃ ʒ ʕ*. Only *ʃ* appears in native Hebrew words, while *ʕ* and *ʒ* are restricted to non-native words (e.g. *ʕip* 'chip', *ʒip* 'jeep', see also Cohen this volume

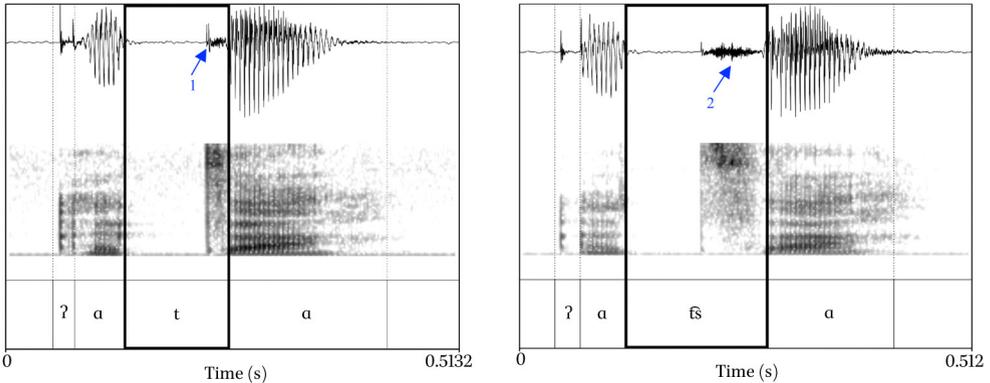


FIGURE 7 Amplitude and spectrogram of a plosive *t* and an affricate *ts*. Spectrogram range: 0–5,000 Hz

on loanwords). Although they have a plosive-like component and a fricative-like component, Hebrew affricates behave as a single segment with respect to phonological processes (Boložky 1980).

Figure 7 compares the alveolar voiceless plosive *t* and the alveolar voiceless affricate *ts*. (1) shows the relatively brief release of the plosive, compared to (2), which demonstrates the prolonged fricated offset of the affricate, extending over approximately half of the duration of the consonant's constriction.

In addition, there are also two **nasal** consonants in Hebrew: *m n*. As opposed to plosives, nasals are stop consonants during which the velum is lowered, allowing the airflow to pass through the nasal passage. Therefore, there is continuous airflow through the nasal passage throughout the duration of the oral closure.

Figure 8 shows the alveolar voiced nasal stop *n* alongside the alveolar voiced oral stop *d*. During the constriction in nasals, the continuous airflow is evident, as there is no decline in the consonant's intensity (1). During the plosive's constriction, however, there is no airflow, and the vocalization of the vocal folds drops gradually throughout the closure (2), resulting in a subsequent decline in the consonant's intensity (as the supra- and sub-glottal pressures reach equilibrium and the pressure builds up behind the closure), and the plosion at the end of the constriction upon release (3). Note, as there is continuous airflow with the nasal, there is no pressure buildup and, subsequently, no plosion at the nasal's release (4).

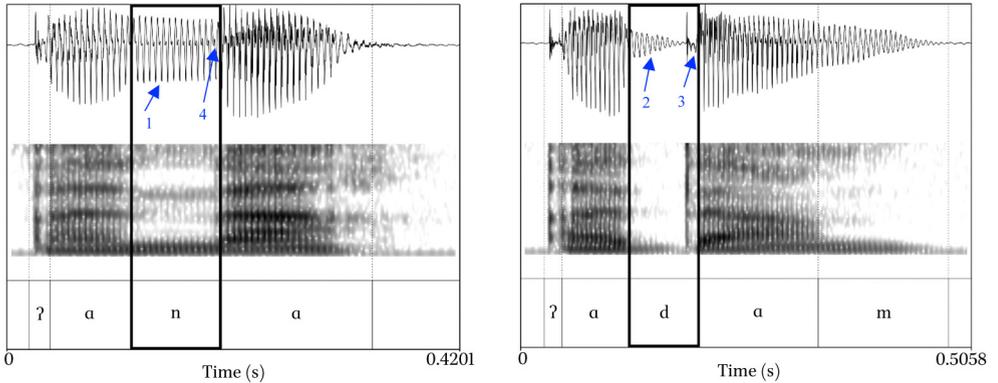


FIGURE 8 Amplitude and spectrogram of a nasal stop *n* and a plosive *d*. Spectrogram range: 0–5,000 Hz

3.2.2 Fricatives

There are eight fricatives in Modern Hebrew: *f v s z ʃ χ h*.⁹ In the Mizrahi Israeli pronunciation of Hebrew, there are two additional fricatives: *ħ ʕ* (see our note on Hebrew pharyngeals in the beginning of this section).¹⁰ The glottal fricative *h* has questionable phonemic status—see § 3.1.4 above. The post-alveolar *ʃ* is the only non-native fricative, though it appears in native words as an allophone of *f* (§ 3.3).

Figure 9 compares two voiceless fricatives which differ in place of articulation, *f* and *χ*. The fricatives differ in their spectral properties, centers of gravity and intensities, reflecting their different places of articulations and degrees of friction. Note how the intensity of *f* (1) is considerably lower than that of *χ* (2), reflected in *f*'s lower amplitude. Note too how the spectral energy of *χ* (3), the dark areas in the spectrogram, is relatively concentrated as opposed to that of *f* (4), which is quite diffuse, spread more evenly over the entire audible spectrum.

3.2.3 Approximants

There are four approximant consonants in Hebrew: *l ʃ j w*. The labio-velar approximant *w* almost only appears in loanwords (see Cohen this volume on loanwords). The approximants differ in places of articulation (alveolar *l*, palatal *j*, labio-velar *w*, uvular *ʃ*) and laterality (lateral *l*, central *j w ʃ*).

9 Laufer (1990, 2008) characterizes the uvular voiceless fricative *χ* as a fricated trill (also see Gafter 2014), though this was not evident in the productions of our informant. In addition, the uvular voiced approximant *ʃ* is sometimes characterized as a fricative (see Cohen et al. this volume).

10 Laufer (1996) claims that *ʕ* is an approximant.

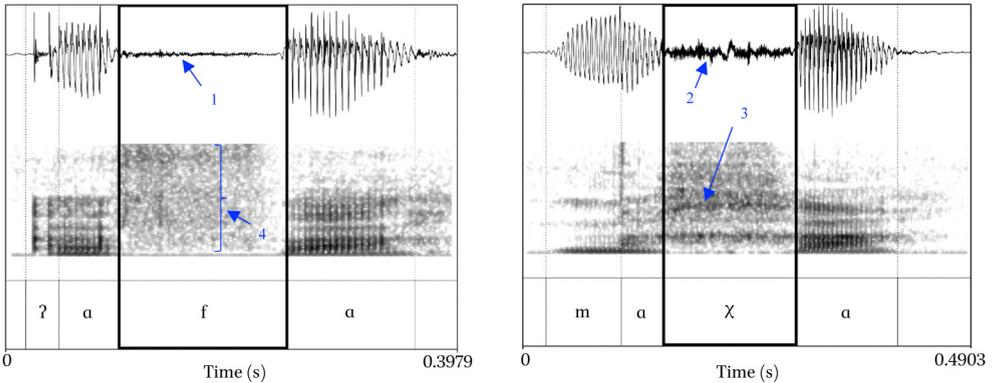


FIGURE 9 Amplitude and spectrogram of fricatives *f*, *χ*. Spectrogram range: 0–5,000 Hz

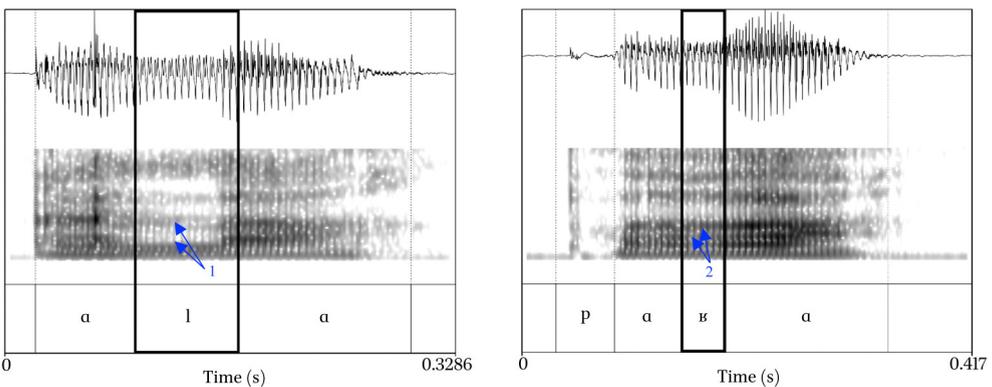


FIGURE 10 Amplitude and spectrogram of approximants *l*, *ʁ*. Spectrogram range: 0–5,000 Hz

Although the rhotic *ʁ* is overwhelmingly an approximant, it may undergo fortition, particularly in word-initial position, resulting in various non-approximant allophones, such as fricatives, trills, flaps and even plosives (see Cohen et al. this volume).

The lateral approximant *l* is characterized by a mid-sagittal occlusion of the vocal tract with airflow around one or both sides of the occlusion. The other approximants (and, in fact, all other consonants in Hebrew) are central.

Figure 10 compares the alveolar lateral approximant *l* and the uvular central approximant *ʁ*. Note the different formant structure of the two consonants. The lateral's first and second formants are more distant from one another (1) compared to the rhotic's (2), which is expected primarily due to their different places of articulation (the uvular rhotic vs. the alveolar lateral).

Figure 11 compares the palatal approximant *j* and the labio-velar approximant *w*. The distance between the first and second formants is much greater

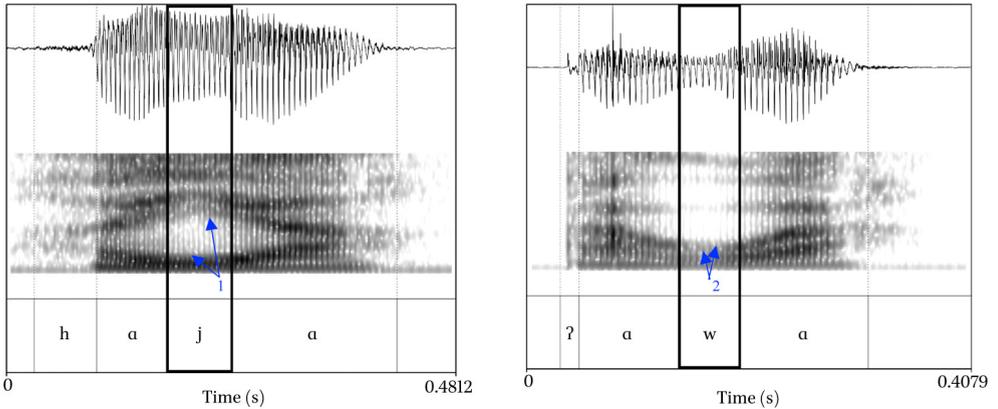


FIGURE 11 Amplitude and spectrogram of approximants *j*, *w*. Spectrogram range: 0–5,000 Hz

for *j* (1) compared to *w* (2). This is comparable to the spectral difference of the correlating vowels *i* (for *j*) and *u* (for *w*); see the vowel plot in § 4.

3.3 Voicing

Hebrew has a two-way voicing contrast in obstruent consonants, including plosives, fricatives and affricates. The voicing contrast is preserved, to some extent, in all prosodic environments, including word-initial, intervocalic, and word-final, and before and after a consonant, although voicing assimilation can occur optionally (Marbé 1971, Bolozky 1977, 2006, Mizrachi 2016, this volume). Consonant voicing is expressed with vibration in the vocal folds during the constriction. Voiced consonants have negative Voice Onset Timing (henceforth: VOT or Voice Onset; Liskin & Abramson 1964), i.e. the vibrations in the vocal folds begin before the transition to the next consonant/vowel (and before the release in plosives). In addition, voiced consonants are usually shorter than their voiceless counterparts, and vowels are usually shorter before a voiced consonant than before a voiceless consonant. Sonorants do not contrast in voicing.

A contrast between the two alveolar plosives, *t* and *d*, is shown in Figure 12. In voiced plosives, the vibration of the vocal folds persists throughout most or all of the closure (1), such that VOT is negative. Voiceless plosives are slightly aspirated (2), i.e. VOT is positive, where *k* has a larger VOT than *p* and *t*. In word-final position, voicing often extends beyond the release of the plosives; this is true even in absolute final position, at the end of an utterance (see below on Laufer 1993, 1998). As for duration, both the closure and the release are longer in voiceless plosives than in voiced plosives. Mizrachi (2016, this volume) found

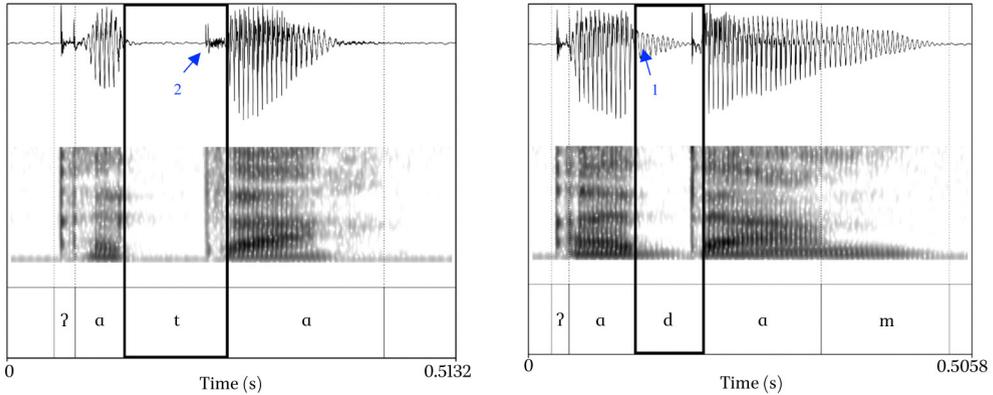


FIGURE 12 Amplitude and spectrogram of voiceless and voiced plosives *t*, *d*. Spectrogram range: 0–5,000 Hz

that in plosives in post-consonantal position, this duration contrast is preserved even in cases of (optional) progressive assimilatory devoicing, in which the vibration of the vocal folds is absent, e.g. /*ekdáχ*/—[*ektáχ*] ‘gun’.

Voicing contrast also extends to some, but not all, fricatives and affricates. There are two pairs of native Hebrew fricatives that contrast in voicing, *f-v* (*kaf* ‘spoon’ vs. *kav* ‘line’) and *s-z* (*saf* ‘minister’ vs. *zaf* ‘stranger’). The voiced counterpart of *f*, i.e. *z*, appears contrastively only in loanwords, such as *zakét* ‘jacket’, *zuḡnál* ‘journal’, and *bagáz* ‘car trunk’. In native words, it only surfaces when *f* undergoes voicing assimilation, e.g. *χefbón* ~ *χezbón* ‘arithmetic’. The uvular fricative *χ* does not have a voiced counterpart. The uvular approximant *ʁ* is sometimes produced as a voiced fricative, especially word-initially (Cohen et al. this volume), and thus is considered by some to be *χ*’s voiced counterpart (e.g. Chayen 1972); however, unlike other obstruent pairs that minimally contrast in voicing, *χ* and *ʁ* can appear adjacent to one another in consonant clusters, e.g. *maxḡív* ‘destroys’ (cf. illicit **masziv*, **matdiv*, **mafiv*).¹¹ The only native affricate, *ʃ*, does not have a voiced counterpart. Hebrew does, however, have a voicing contrast among its two post-alveolar counterparts *tʃ* and *dʒ* (*tʃip* ‘chip’ vs. *dʒíp* ‘jeep’).

The voicing contrast among the alveolar fricatives *s-z* is shown in Figure 13. Like voiced plosives, voiced fricatives are characterized by vibrations of the vocal folds throughout the constriction, as well as shorter duration overall compared to their voiceless counterparts.

11 See Schwarzwald (2005), Bolozky (2006) and Asherov & Bat-El (this volume) on restrictions on consonant clusters.

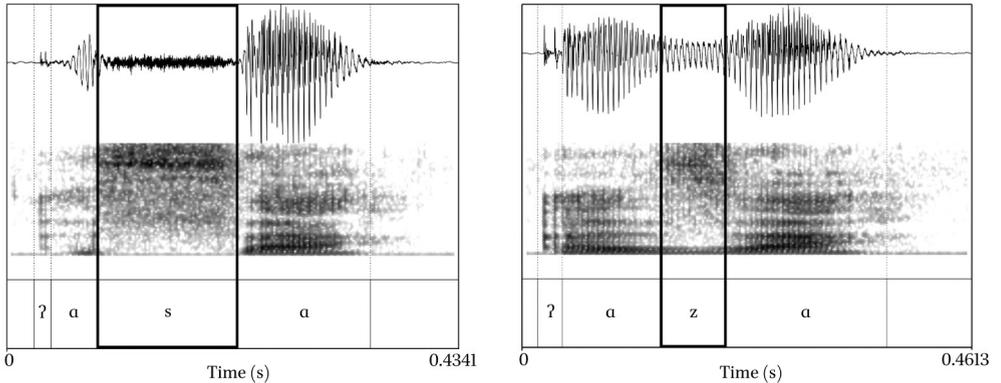


FIGURE 13 Amplitude and spectrogram of voiceless and voiced fricatives *s, z*. Spectrogram range: 0–10,000 Hz

Laufer (1993, 1998) conducted a series of acoustic studies of voicing in the six Hebrew plosives (*p-b, t-d, k-g*).¹² We report here the results of one of his experiments, in which ten native speakers of Hebrew produced 40 minimal pairs in isolation; 25 with a word-initial plosive and 15 with a word-final plosive. Voicing in initial plosives was measured by VOT, i.e. the onset of voicing with respect to the release, while voicing in final plosives was measured by the offset of voicing with respect to the release (henceforth: Voice offset). The results are presented in Figure 14.

In initial plosives (on the left), all voiced plosives had negative VOT ($M = -8.7$ ms, $n = 120$) and all voiceless plosives had VOT of 0 or greater ($M = 3.8$ ms, $n = 120$). The voice offset in final voiced plosives (on the right) was usually after the closure ($M = 1.6$ ms, $n = 78$), and the offset of voicing in final voiceless plosives was far earlier ($M = -11.7$, $n = 80$).

4 Vowels

Hebrew has five vowels, presented in Table 2. The vowels are distinguished by three levels of height: high *i, u*, mid *e, o*, and low *a*. Among non-low vowels, back vowels *u, o* are rounded and front vowels *i, e* are unrounded. The low vowel *a* is usually described as central (e.g. Laufer 1990) or back (e.g. Cohen 2009), though front variants have also been reported (Chayen 1972, 1973, Marbé 1971). Hebrew

¹² Other acoustic studies of voicing in Hebrew include Devens (1978), Raphael et al. (1983), and Raphael et al. (1995), among others.

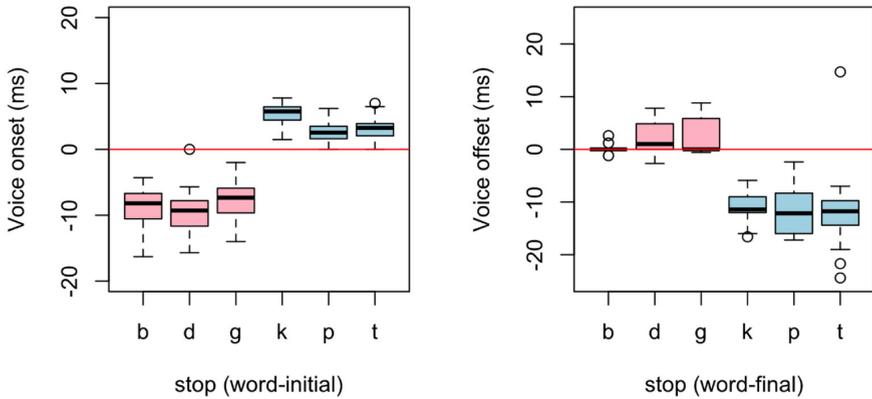


FIGURE 14 Measurements of voicing in plosives. Boxes span over the 25%–75% interquartile range (IQR). The line across each box indicates the median. Whiskers show the highest and the lowest observations within the ranges of 1.5 times the IQR above 75% and below 25%, respectively. Individual data points beyond this range are marked with circles.
 DATA FROM LAUFER 1993, 1998

TABLE 2 Vowel inventory

	front	central	back
high	i		u
mid	e		o
low		ɑ	

does not have a phonemic contrast in duration, nasality or tenseness. All vowels are generally voiced, but they may undergo devoicing in rapid speech when surrounded by voiceless consonants (*tapuxéj adamá* ‘potatoes’).

Hebrew diphthongs are always analyzed as a sequence of a vowel and a glide (Marbé 1971), where a glide is defined as one of the approximants *j* or *w*.¹³ The sole native glide *j* can combine with each of the five Hebrew vowels to create falling diphthongs (e.g. *gaj* ‘valley’, *noj* ‘beauty’), though *ij* only appears in non-final unstressed environments (e.g. *ijmú* ‘they threatened’). Similarly, rising diphthongs are also possible (e.g. *jad* ‘hand’, *jom* ‘day’), but *ji* is simplified

13 As opposed to a complex syllable nucleus (Marbé 1971); also see Asherov & Bat-El (this volume).

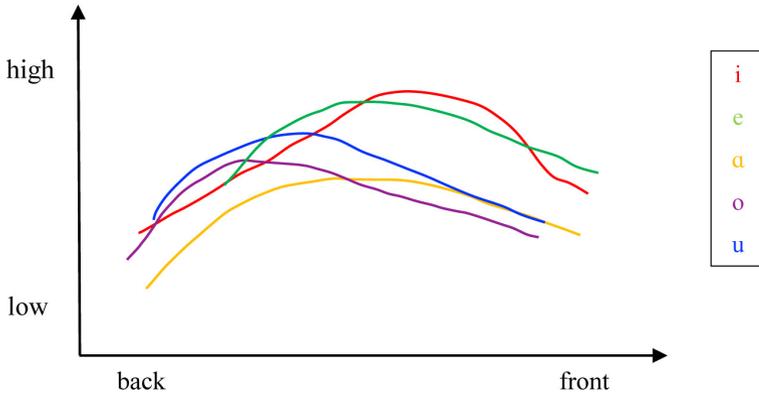


FIGURE 15 Tongue shape of the five vowels *i*, *e*, *a*, *o*, *u*. Tongue surface is rotated 15° from raw frames (see Appendix II).

to *i* by many speakers (*jifšúš* ~ *ifšúš* 'manufacturing'). Similarly to *j*, the non-native labio-velar glide *w* appears in some falling diphthongs (*šow* 'show', *waw* 'wow'), and some rising diphthongs (*wiški* 'whiskey', *wála* 'you don't say!').¹⁴

Vowels do not contrast in duration. Consecutive identical vowels are allowed, e.g. *šeelá* 'question' (cf. *šelá* 'hers'), *šáam* 'thunder' (cf. *šam* 'high'), but they are always parsed into different syllables (Marbé 1971). Vowel duration is, however, the primary cue for word-level stress (Cohen et al. 2018, Bat-El et al. this volume).¹⁵ Hebrew has lexical stress, and words can be distinguished solely based on the position of stress, e.g. *bókeš* 'morning' vs. *bokéš* 'cowboy'. In fact, stress can appear on any syllable in loanwords, e.g. *béjbisiteš* 'babysitter' (4th from the right edge). The stressed vowel is the longest among the syllables in words with final or penultimate stress; in words with antepenultimate stress, the vowel in the final syllable is longer. With the exclusion of word-final lengthening, vowel duration decreases with distance from the stressed vowel, and there is no evidence for secondary stress. Unstressed vowels are generally not centralized; however, they may undergo deletion or assimilation in rapid speech (Boložky 1977, this volume, Boložky & Schwarzwald 1990).

Figure 15 shows the tongue shapes of the five vowels produced by our informant. While the interpretation of vowel backness in articulatory terms is not straightforward (Ladefoged 1967, Ladefoged & Maddieson 1996, Ladefoged & Disner 2012), we see that the position of the tongue body in *i, e* is further front

14 Older speakers adapt the non-native approximant *w* to the native fricative *v*, e.g. *viški* 'whiskey'.

15 See Tene (1962) and Marbé (1971) for early descriptions of the correlation between vowel duration and stress, and of word-final lengthening in Hebrew.

than that in *a, o, u*. We also see that *i* is further front than *e*, and *u* is further front than *o*. As for vowel height, among front vowels, *i* is higher than *e*; among non-front vowels, *u* is higher than *o*, which is in turn higher than *a*.

Most et al. (2000) analyzed the vowel productions of 90 native speakers of Hebrew: 60 adults and 30 nine-year-old children, balanced in gender (30 men, 30 women, 15 boys, 15 girls).¹⁶ Participants produced five nonce words of the form CVC, where each of the five vowels occupied V in one of the words, and the consonant *p* occupied both consonantal positions. The words were embedded in a carrier sentence in Hebrew *hamoʕa katva ___ al haluax* ‘The teacher wrote ___ on the board’, where ___ was occupied by the nonce word. Each sentence was produced five times, yielding 25 vowel tokens per speaker. Among other acoustic properties, Most et al. measured the frequencies of the first and second formants, extracting the values from the middle of the steady state part of the vowel. The first formant (F1) roughly correlates with vowel height, and the difference between the second and the first formant (F2-F1) roughly correlates with vowel backness (Ladefoged 1975). Based on their data, Figure 16 presents the mean values of F1 (ordinate) and F2-F1 (abscissa) of each of the five Hebrew vowels in the two adult groups (men and women).

Mirroring the articulatory space in Figure 15, the vowels *i, e* (front vowels) have larger F2-F1 values than *u, o, a* (non-front vowels). Within front vowels, *i* has larger F2-F1 value than *e*. Men and women seem to differ with respect to the relative mean values of F2-F1 in the three non-front vowels. Most notably, the mean F2-F1 of *a* is considerably larger than that of *u* and *o* in women’s productions, but not in men’s. We refer the reader to Most et al.’s (2000) paper for an extensive discussion of differences among speakers by age and gender.

5 Conclusions

This paper provides an overview of the phonetic properties of Modern Hebrew segments. Consonants contrast in place of articulation, manner of articulation and voicing. Consonants are produced by creating a constriction in one of eight places of articulation (§ 3.1), such that consonants can be bilabial, labio-dental, alveolar, post-alveolar, palatal, velar, uvular or glottal (and also both bilabial and velar: *w*). Some speakers also have pharyngeal consonants in their inven-

16 Other acoustic studies of Hebrew vowels include Tene (1962), Enoch & Kaplan (1969), Laufer (1972), Schwarzwald (1972), Marbé (1971), Devens (1978), Aronson et al. (1996), and Maymon (2001).

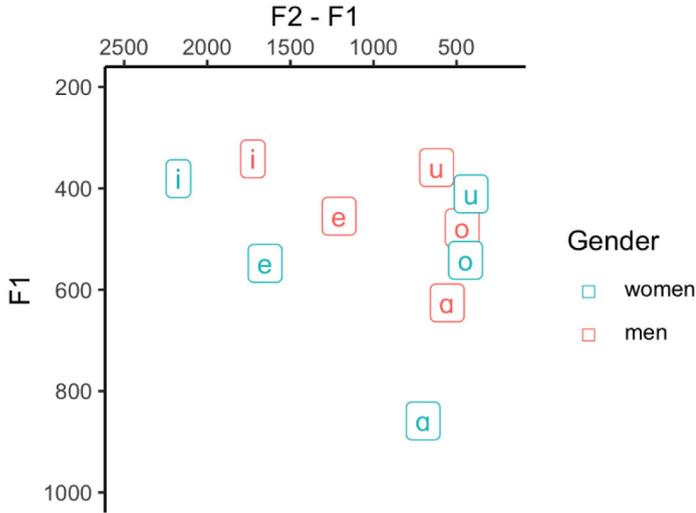


FIGURE 16 Acoustic vowel space by gender
DATA FROM MOST ET AL. 2000

tory. The manner of articulation (§ 3.2) is determined by the degree of closure, the laterality of the constriction, the presence or absence of airflow through the nasal passage, and the type of offset. Obstruents have a two-way voicing contrast (§ 3.3), and sonorants are always voiced. Vowels (§ 4) are distinguished by three levels of height (high, mid, low) and by backness (front, back). Non-low back vowels are rounded.

References

- Albert, Aviad. This volume. The State of Stop-Fricative Alternation in Modern Hebrew.
- Aronson, L., J. Rosenhouse, G. Rosenhouse, & L. Podoshin. 1996. An acoustic analysis of modern Hebrew vowels and voiced consonants. *Journal of Phonetics* 24(2), 283–293.
- Ashero, Daniel & Outi Bat-El. This volume. Syllable Structure and Complex Onsets in Modern Hebrew.
- Bassel, Noa. & Si Berrebi. 2016. *Pharyngeal minds: a perception study of variation in Modern Hebrew*. Talk given at Rencontres d'Automne de Linguistique formelle: Langage, Langues et Cognition (RALFe), November 3–4. CNRS, Paris.
- Bat-El Outi, Evan-Gary Cohen, & Vered Silber-Varod. This volume. Modern Hebrew Stress.
- Blanc, Haim. 1968. The Israeli Koine as an emergent national standard. In *Language*

- Problems of Developing Nations*, eds. Joshua A. Fishman, Charles Albert Ferguson & Jyotirindra Das Gupta. New York: Wiley. 237–251.
- Boersma, Paul. 1998. *Functional phonology: Formalizing the interactions between articulatory and perceptual drives*. The Hague: Holland Academic Graphics.
- Boersma, Paul & David Weenink. 2016. Praat: doing phonetics by computer [Computer program]. Version 5.4.20. Available from <http://www.praat.org/>.
- Bolozky, Shmuel. 1977. Fast Speech as a Function of Tempo in Natural Generative Phonology. *Journal of Linguistics* 13(2), 217–238.
- Bolozky, Shmuel. 1978. Some aspects of Modern Hebrew phonology. In *Modern Hebrew Structure*, ed. Ruth Aronson Berman. Tel Aviv: Universities Publishing Projects. 11–67.
- Bolozky, Shmuel. 1980. On the monomorphemic interpretation of Modern Hebrew affricates. *Linguistic Inquiry* 11, 793–799.
- Bolozky, Shmuel. 1997. Israeli Hebrew phonology. In *Phonologies of Asia and Africa Vol. 1*, eds. Alan S. Kaye & Peter T. Daniels. Winona Lake, Indiana: Eisenbrauns. 287–311.
- Bolozky, Shmuel. 2006. A note on initial consonant clusters in Israeli Hebrew. *Hebrew Studies* 47, 227–235.
- Bolozky, Shmuel. This volume. The Phonology of Connected Speech in Israeli Hebrew.
- Bolozky, Shmuel & Ora Rodrigue Schwarzwald. 1990. On vowel assimilation and deletion in casual Modern Hebrew. *Hebrew Annual Review* 12, 23–48.
- Chayen, Maurice J. 1972. Israeli Hebrew pronunciation (in Hebrew). *Lěšonénu* 36, 212–219.
- Chayen, Maurice J. 1973. *The Phonetics of Modern Hebrew*. The Hague, Paris: Mouton.
- Cohen, Evan-Gary. 2009. *The role of similarity in phonology: Evidence from loanword adaptation in Hebrew*. PhD dissertation, Tel-Aviv University.
- Cohen, Evan-Gary. This volume. Loanword Phonology in Modern Hebrew.
- Cohen, Evan-Gary, Lior Laks & Carmen Savu. This volume. The Phonetics of Modern Hebrew Rhotics.
- Cohen, Evan-Gary, Vered Silber-Varod & Noam Amir. 2018. The acoustics of primary and secondary stress in Modern Hebrew. *Brill's Annual of Afroasiatic Languages and Linguistics* 10, 1–19.
- Devens, Monica Schaefer. 1978. *The Phonetics of Israeli Hebrew: "Oriental" versus "General Israeli Hebrew"*. PhD thesis, University of California Los Angeles.
- Devens, Monica Schaefer. 1983. Interdental Variants of Denti-alveolar Consonants in Israeli Hebrew (in Hebrew). *Lěšonénu* 47, 289–290.
- Enguehard, Guillaume & Noam Faust. 2018. Guttural ghosts in Modern Hebrew. *Linguistic Inquiry* 49(4), 685–721.
- Enoch, P. & Kaplan, G. 1969. The Physical Nature of Syllabic Stress in Israeli Hebrew (in Hebrew). *Lěšonénu* 33, 208–222.

- Faust, Noam. 2005. *The fate of Hebrew gutturals*. MA Thesis, Tel-Aviv University.
- Faust, Noam. This volume-a. Gutturals in General Israeli Hebrew.
- Faust, Noam. This volume-b. Vowel Alternation in Modern Hebrew.
- Gafter, Roey J. 2014. *"The most beautiful and correct Hebrew": Authenticity, ethnic identity and linguistic variation in the greater Tel Aviv area*. PhD thesis, Stanford University.
- Gafter, Roey J. This volume. Modern Hebrew Sociophonetics.
- Kreitman, Rina & Shmuel Bolozky. 2007. *Uvular Segments in Modern Hebrew: Their Phonetic and Phonological Status*. Talk given at NAPH conference meeting, Sydney: Australia.
- Ladefoged, Peter. 1967. *Three Areas of Experimental Phonetics: stress and respiratory activity, the nature of vowel quality, unites in perception and production of speech*. Oxford: Oxford University Press.
- Ladefoged, Peter. 1975. *A course in phonetics*. Orlando: Harcourt.
- Ladefoged, Peter & Ian Maddieson. 1996. *The sounds of the world's languages*. Oxford: Blackwell.
- Ladefoged, Peter & Sandra Ferrari. 2012. *Vowels and consonants* [third edition]. John Wiley & Sons.
- Laks, Lior, Evan-Gary Cohen, & Stav Azulay-Amar. 2016. Paradigm uniformity and the locus of derivation: the case of vowel epenthesis in Hebrew verbs. *Lingua* 170, 1–22.
- Laufer, Asher. 1972. *Synthesis by rule of a Hebrew idiolect*. PhD thesis, University of London.
- Laufer, Asher. 1990. Hebrew. *Journal of the International Phonetic Association* 20(2), 40–43.
- Laufer, Asher. 1991. The 'glottal fricatives'. *Journal of the International Phonetic Association* 21(2), 91–93.
- Laufer, Asher. 1993. Voicing in Contemporary Hebrew (in Hebrew). *Lěšonénu* 57, 299–342.
- Laufer, Asher. 1996. The common [ʕ] is an approximant and not a fricative. *Journal of the International Phonetic Association* 26(2), 113–118.
- Laufer, Asher. 1998. Voicing in contemporary Hebrew in comparison with other languages. *Hebrew Studies* 39(1), 143–179.
- Laufer, Asher. 2008. *Chapters in Phonetics and in Phonetic Transcription* (in Hebrew). Jerusalem: Magnes.
- Laufer, Asher & Thomas Baer. 1988. The Emphatic and Pharyngeal Sounds in Hebrew and in Arabic. *Status Report on Speech Research*, SR-95/96, Haskins Laboratories. 51–71.
- Lisker, Leigh & Arthur S. Abramson. 1964. A cross-language study of voicing in initial stops: Acoustical measurements. *Word* 20(3), 384–422.
- Marbé, Alan Joseph. 1971. *Phonetics of modern Israeli Hebrew*. PhD thesis, University of Edinburgh.

- Matras, Yaron & Leora Schiff. 2005. Spoken Israeli Hebrew Revisited: Structures and Variation. *Studia Semitica: The Journal of Semitic Studies Jubilee Volume*, 145–191.
- Maymon, Yael. 2001. The influence of environment on Hebrew vowels: An acoustic study (in Hebrew). MA thesis, Ben-Gurion University of the Negev.
- Mizrachi, Avi. 2016. *Asymmetry in Voicing Assimilation in Hebrew*. MA thesis, Tel-Aviv University.
- Mizrachi, Avi. This volume. A Note on Modern Hebrew Voicing Assimilation.
- Most, Tova, Ofer Amir, & Yishai Tobin. 2000. The Hebrew vowel system: Raw and normalized acoustic data. *Language and Speech* 43(3), 295–308.
- Raphael, Lawrence J., Yishai Tobin, & Tova Most. 1983. Atypical VOT categories in Hebrew and Spanish. *The Journal of the Acoustical Society of America* 74, S89.
- Raphael, Lawrence J., Yishai Tobin, Alice Faber, Tova Most, H. Betty Kollia, & Doron Milstein. 1995. Intermediate values of voice onset time. In *Producing Speech: Contemporary Issues. For Katherine Safford Harris*, eds. Fredericka Bell-Berti & Lawrence J. Raphael. 117–127.
- Schwarzwald, Ora Rodrigue. 1972. Hebrew and English vowels: A spectrographic study (in Hebrew). *Balshanut Ivrit hapashit* 6, 1–11.
- Schwarzwald, Ora Rodrigue. 1981. *Grammar and reality in the Hebrew verb* (in Hebrew). Ramat Gan: Bar-Ilan University.
- Schwarzwald, Ora Rodrigue. 2005. Modern Hebrew consonant clusters. In *Perspectives on Language and Language development*, eds. Dorit Ravid & Hava Bat-Zeev Shyldkrot. Dordrecht: Kluwer. 45–60.
- Tene, David. 1962. The measured length of the Hebrew vowels (a kymograph study) (in Hebrew). *Lěšonénu* 26, 220–268.
- Yaeger-Dror, Malcah. 1988. The influence of changing group vitality on convergence toward a dominant linguistic norm: An Israeli example. *Language & Communication* 8(3–4), 285–305.
- Yeverechyahu, Hadas. This volume. Consonant Co-occurrence Restrictions in Modern Hebrew.

Appendix I: stimuli

The following list includes transcriptions of the words used to elicit the production of each consonant. The consonants were produced at the onset of a stressed syllable in the environment *a_a* (see details in §2). The five vowels were also recorded in isolation. Glottal consonants were not included. The IPA transcription reflects the actual pronunciation of our informant. The target consonant in each word is marked in bold.

sapá

ʔabá

afá

avá

χamá

atá

adám

asá

aʔsá

azá

aná

alá

paʃá

aʒáf

baʃám

maðzáb

hajá

maká

magáf

maχá

awá

Appendix II: raw ultrasound tongue images

This appendix includes the raw UTI frames used to create the tongue shape plots in this paper. The figures are numbered according to the corresponding tongue shape plot figures, with an addition of an apostrophe.

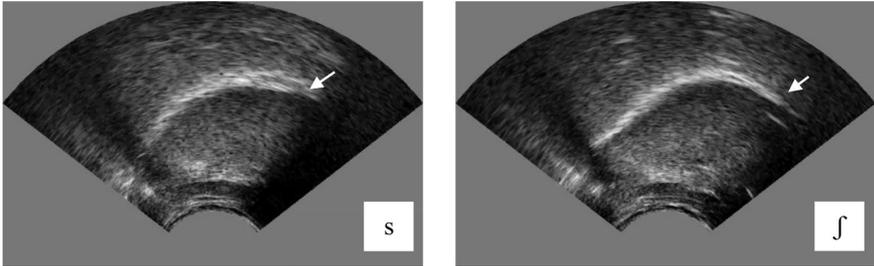


FIGURE 4' UTI of anterior and non-anterior sibilants. White arrow indicates the tongue blade (tongue tip is not clearly observable)

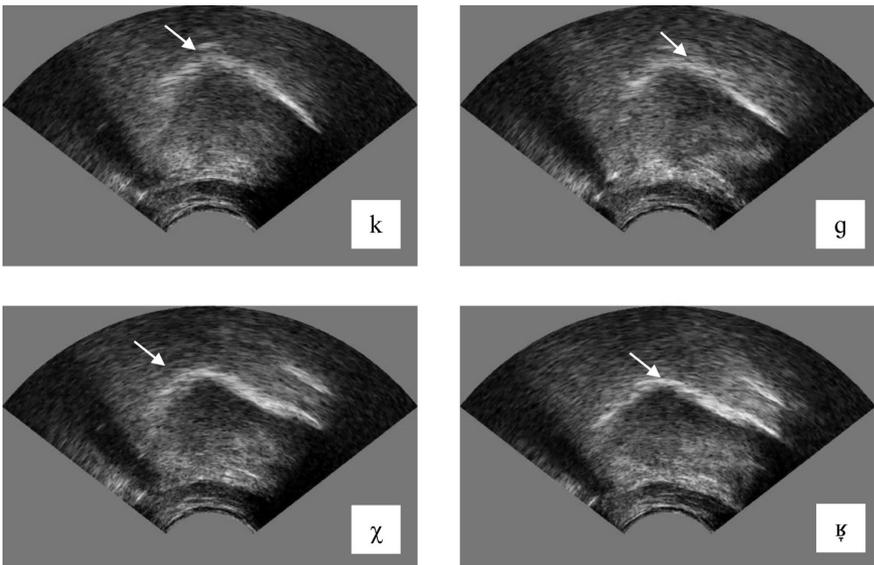


FIGURE 5' UTI of velar and uvular consonants. White arrow indicates the tongue back

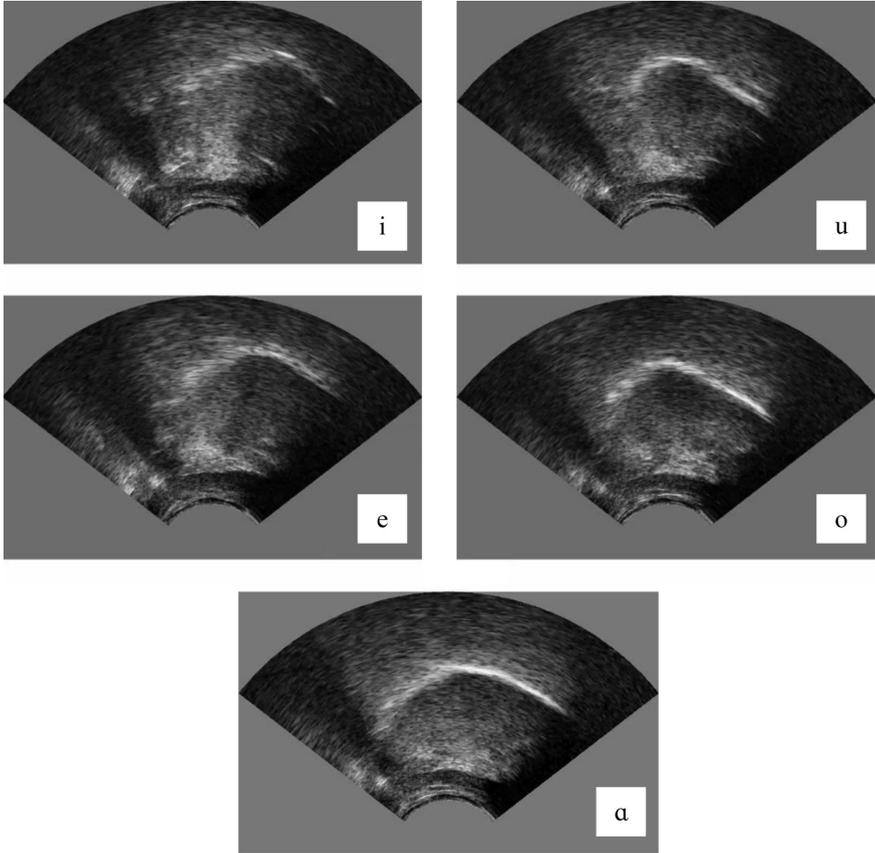


FIGURE 15' UTI of the five vowels