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# Sibilant production in Hebrew-speaking adults: Apical versus laminal

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## ABSTRACT

The Hebrew IPA charts describe the sibilants /s, z/ as ‘alveolar fricatives’, where the place of articulation on the palate is the alveolar ridge. The point of constriction on the tongue is not defined – apical (tip) or laminal (blade). Usually, speech and language pathologists (SLPs) use the apical placement in Hebrew articulation therapy. Some researchers and SLPs suggested that acceptable /s, z/ could be also produced with the laminal placement (i.e. the tip of the tongue approximating the lower incisors). The present study focused at the clinical level, attempting to determine the prevalence of these alternative points of constriction on the tongue for /s/ and /z/ in three different samples of Hebrew-speaking young adults (total  $n = 242$ ), with typical articulation. Around 60% of the participants reported using the laminal position, regardless of several speaker-related variables (e.g. tongue-thrust swallowing, gender). Laminal production was more common in /s/ (than /z/), coda (than onset) position of the sibilant, mono- (than di-) syllabic words, and with non-alveolar (than alveolar) adjacent consonants. Experiment 3 revealed no acoustical differences between apical and laminal productions of /s/ and of /z/. From a clinical perspective, we wish to raise the awareness of SLPs to the prevalence of the two placements when treating Hebrew speakers, noting that tongue placements were highly correlated across sibilants. Finally, we recommend adopting a client-centred practice, where tongue placement is matched to the client. We further recommend selecting targets for intervention based on our findings, and separating between different prosodic positions in treatment.

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## Introduction

The Hebrew IPA (International Phonetic Alphabet) charts present the place of articulation of the sibilants /s/ and /z/ as ‘alveolar fricatives’ (Ladefoged, 1993; Laufer, 1999). In other words, their place of articulation on the palate is the alveolar ridge. However, the point of constriction on the tongue (tip or blade) is not defined. Using the tip of the tongue is referred to as *apical*. By raising the tongue-tip against the roof of the mouth (at the level of the upper front teeth), a narrow constriction is formed in the lingua-alveolar region of the

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oral cavity, which is adjusted so that the airstream emerging from it impinges on the incisors (Kent & Read, 2002; Nozaki, Yoshinaga, & Wada, 2014). Yet, it seems that many languages are characterised by a wide variation in the pronunciation of /s/ and /z/ (e.g. English – Ladefoged & Maddieson, 1996; Spanish – Obaid, 1973; Japanese – Raver-Lampman, Toreno, & Bing, 2015).

Currently, there are missing data in Hebrew regarding the prevalence of various points of constriction on the tongue of these sibilants, specifically, the *laminal* ('blade') variant. In their absence, SLPs generally instruct Hebrew speakers to articulate these alveolar fricatives using the apical placement (presumably, because this is the more common placement in English; Dart, 1998). This placement may not be optimal for all speakers, delaying the achievement of therapeutic goals and increasing frustration of both therapists and clients (Raver-Lampman & Dossou, 2011). The goal of the present study was to estimate the prevalence of the two alternative points of constriction on the tongue with native Hebrew speakers, using impressionistic measurement (as routinely used in the clinic). Results carry important clinical implications for speech (articulation) therapy with Hebrew-speaking clients and provide useful guidelines for intervention programmes. SLPs can use a similar methodology in the clinic to easily evaluate the patient's most comfortable, yet acceptable, place of articulation and successfully guide speech rehabilitation.

### ***Apical tongue placement at sibilant articulation***

Raver-Lampman et al. (2015) noted that 'The English /s/ sound was described as an alveolar fricative, meaning that the tongue tip turns upward, approaching the alveolar ridge' (p. 238). This 'classic' apical position of the tongue-tip during the production of /s, z/ in several languages has been confirmed by studies that used electropalatography (EPG), in which intra-oral electrodes recorded the contact points at which the tongue touches the palate (e.g. English – Cheng, Murdoch, Goozee, & Scott, 2007; Chinese – Hu, 2008). Following this standard description of the tongue position during sibilant articulation, speech and language pathologists (SLPs) usually use the apical position to correct misarticulations such as lateral lisps (Bowen, 1999).

Many traditional articulation-therapy programmes are focused on phonetic placement cues, according to phonetic-based practice principles described by Van Riper (1978). An upper tongue-tip placement configuration is considered a helpful training tool in remediating misarticulated /s/ and /z/ (McAuliffe & Cornwell, 2008). These therapy principles are prevalent to this day. For example, Rogers and Chesin (2013) used such traditional phonetic-based treatment for their control group of school-aged children who misarticulated /s/. In each session, each stimulus item began with phonetic placement techniques that described and visually illustrated to the participant correct placement.

Tongue placement is a crucial factor in correct articulation. The necessary oral constriction will not be achieved if the precise placement of the tongue is not realised. As a result, the production of /s/ or /z/ may sound distorted to the listener (Kent & Read, 2002; Stone et al., 2012). Thus, placements of sibilant articulation that are not apical are often described as *variants*. An improper tongue position may result in articulation disorders (Daniloff, 1980; McGlone & Proffit, 1973; Mowrer & Sundstrom, 1988). For example, lisp (sigmatism) is the result of lateral or interdental misarticulation (McAuliffe & Cornwell, 2008).

### ***Laminal tongue placement at sibilant articulation***

Considering the current literature, the picture appears to be more complex, as the apical production of the two sibilants may not be as frequently used in natural speech as previously described. Just as some individuals have a high tongue-tip position at rest, while others show a low position, some speakers with typical articulation produce /s/ and /z/ with a raised tongue-tip, whereas others with a *lowered* tongue-tip (Lebrun, 1985). For example, Cruttenden (2014) describes the alveolar English consonants /t, d, l, n, s, z/ as being produced with either the blade or tip and blade of the tongue against the alveolar ridge.

Such reports led to the assertion that an alternative tongue placement, referred to as *laminal*, can yield an acceptable /s/ and /z/, perceived as correct and native by listeners. Producing a laminal /s/ or /z/, the tongue-tip is lowered toward the lower teeth and the blade forms the point of constriction against the alveolar ridge (Dart, 1998). Importantly, Stoner, Gately and Rivers (1987) found no perceptual or acoustic differences between apical and laminal /s/ productions in English (see also: Karlsson, Shriberg, Flipsen, & McSweeney, 2002).

Laminal sibilant production has been found in several languages. English /s/ and /z/ could be either apical or laminal (Dart, 1998). Stone et al. (2012), in a cine-MRI study, found that 12 of the 22 English speaking control participants (about 55%) used the apical variant for /s/ production. In French, sibilants were found to be generally articulated with a lowered tongue-tip (using cineradiography; Simon, 1967, in: Lebrun, 1985). Similarly, in a literature review of studies in French, Dart (1998) found that the majority of the sources reported a tip-down laminal tongue position for the sibilants /s/ and /z/, and the minority reported either dental or alveolar placements. A comparable pattern was noted in German, where 87.5% of a sample of German children were found to use a low apex position rather than a high one (Weinert, 1963; Kramer, 1967, in: Lebrun, 1985). Toda, Maeda, and Honda (2010) used MRI data and reported that the Polish sibilant /s/ has a front constriction with the tongue in contact with the internal surface of the lower incisors. The Japanese /s/ sound may be also articulated in a laminal position, with the tongue-tip pointed downwards (Raver-Lampman et al., 2015). These findings highlight the considerable inter-language variation in two factors, place of articulation on the palate and point of constriction on the tongue. This inter-language variation is added to the individual and intra-speaker variation, as will be discussed in the next section (see, Munson, 2004).

The primary goal of the current study was to gauge the frequency of the two alternative tongue-tip placements in the sibilant production of Hebrew speakers. Currently, data regarding tongue-tip placement in sibilant articulation in Hebrew are not available. Note, a recent study by Cohen, Savu, and Laks (2015) investigated manner variation of Israeli Hebrew rhotics and found prosodic and gender effects on their production (see also: Cohen, 2015). As the Hebrew IPA charts (Laufer, 1999) describe an alveolar placement for the sibilants /s/ and /z/, SLPs are instructing and demonstrating the common apical position during therapy for Hebrew speakers. However, clinical impressions of many Israeli SLPs (including the first author of this study, with over 20 years of clinical experience) raise the option that Hebrew speakers frequently use the laminal position. If these impressions were to be supported in the current study, SLPs should consider this alternative tongue-tip placement while instructing patients on correct articulation. Obviously, SLPs rely on knowledge of tongue placement to assess and provide

intervention. Yet, Mcleod (2011) found SLPs to demonstrate poor knowledge of tongue/palate contact for consonants along the lateral margins of the palate, including /s/ and /z/. The author concluded that ‘awareness of coronal tongue placement for consonant production needs targeting in SLP education’. Following this clinical recommendation, the present study was conducted, in order to raise SLPs’ awareness for the laminal point of constriction on the tongue for sibilant production in Hebrew.

Shedding light on this issue is especially important, as the sibilant /s/ is ranked as one of the most frequently misarticulated consonants in many languages (Thorun, 2012), English (Mowrer & Sundstrom, 1988), Dutch (Van Borsel, Rentergem, & Verhaeghe, 2007), Korean and Chinese (Fox & Jacewicz, 2009; Iverson & Lee, 2006; Molholt, 1988) and Arabic (Alaraifi, Amayreh, & Saleh, 2014). The treatment of /s/ misarticulation is often reported as frustrating for SLPs (Raver-Lampman & Dossou, 2011) and not always successful (Daniloff, 1980).

### ***Possible variables that may affect tongue-tip placement in sibilant production***

The second goal of this study was to evaluate several variables that may lead to higher frequency of apical or laminal articulation of sibilants. These include speaker-related variables: tongue-thrust, ankyloglossia and gender; and stimulus-related variables: word length, sibilant location and coarticulation.

#### ***Speaker-related variables***

In typical swallowing, the tongue-tip elevates towards the superior alveolar tissue or the lingual surface of the upper incisors. By contrast, in tongue-thrust (a-typical) swallowing, the tongue protrudes through the anterior incisors. This pattern often occurs during speech and is often related to genetic factors and learned behaviours (Tarvade & Ramkrishna, 2015). Tongue thrust has also been associated with ankyloglossia – tongue-tie (a tight lingual frenulum; Tuerk & Lubit, 1959). Presumably, restriction of the upward and backward movement of the tongue (as in the presence of ankyloglossia) may result in exaggerated tongue thrusting (see Bhattad & al., 2013; Jang et al., 2011).

The maintenance of tongue-thrust swallowing during childhood and adolescence depends on the rest position of the tongue in the mouth (Nijdam & Teunissen, 1981). If at rest the tongue-tip lies against the lingual aspect of the upper incisors or against the upper alveolar ridge, then the swallow will be typical. If at rest the tongue-tip lies elsewhere in the mouth, swallowing will be a-typical. Tongue-tip position at rest and at swallowing may relate to tongue-tip position at speech. Specifically, in sibilant production, one may assume that typical (alveolar) swallowing will correlate with an apical production, whereas tongue-thrust (non-alveolar) and/or ankyloglossia will correlate with a laminal position. Accordingly, in Experiment 2, we evaluated the swallowing pattern and the lingual frenulum of all participants. Finally, biological sex may affect sibilant production as well, related to differences in the size of the resonating cavity anterior to the point of constriction. Indeed, several studies in different languages/dialects (Glaswegian: Stuart-Smith, Timmins, & Wrench, 2003; New Zealand English dialects: Starks, 2000; English: Flipsen, Shriberg, Weismer, Karlsson, & McSweeney, 1999) showed gender differences in sibilant production (tongue tip placement and acoustic characteristics).

### **Stimulus-related variables**

Factors such as word length (monosyllabic, disyllabic), sibilant location (onset, coda; Cohen & Ben-David, 2016) and coarticulation (adjacent consonants) may also affect tongue-tip placement at sibilant production. During speech production, talkers produce vocal tract gestures (coordinated actions of the articulators, or spatio-temporal units; Gafos, 2002) for consonants and vowels in overlapping time frames – *coarticulation*. In other words, one begins producing a gesture for a segment, while the gestures of the former segment are still ongoing (anticipatory coarticulation). Similarly, one completes a segment's gesture after the gestures for the next segment have begun (carryover or perseveratory coarticulation; Fowler, Brown, & Mann, 2000). Due to this spatial and temporal overlap of adjacent articulatory activities, the speech signal is context-dependent, and phoneme production varies substantially, depending on surrounding phonemes (Lotto & Kluender, 1998) and on their syllabic position (Byrd, 1996; Krakow, 1999).

Coarticulation well explains differences in articulation patterns. For example, Mann (1980) showed that the articulation of the consonants /g, d/ was influenced by the production of the preceding /r, l/. It is reasonable to assume that coarticulatory influence operates at sibilant production as well. As recently suggested by Nozaki et al. (2014), tongue-tip placement at /s, z/ production may be affected by the preceding or succeeding consonant. Specifically, we assume that a non-alveolar adjacent consonant (e.g. /m, g, k, ʁ/) might result in a laminal production of the near sibilant (presumably, this might be the default tongue-tip placement, as in French; Dart, 1998). However, an adjacent alveolar consonant, characterised by an apical tongue-tip placement (e.g. /l, d, t/), might affect the near sibilant, resulting in an alternative apical sibilant production. Interestingly, Tabain (2001) suggested that sibilants may be resilient to such coarticulatory effects. This possible inconsistency calls for a further examination, as conducted in Experiment 2, where we directly test the effects of these variables on sibilant production among adult Hebrew speakers.

### **The current study**

The current study focused on the clinical level (rather than the theoretical-linguistic perspective). It aimed to clarify the tongue-tip placement at the production of /s, z/ among young adult Hebrew speakers. Such data are currently missing from the literature. Thus, speech (articulation) intervention programmes are based on the apical placement (presumably, following data in English; Dart, 1998). The current study closely follows the work by Raver-Lampman and Dossou (2011, see also Taylor, 1998; Starks, 2000) that used an impressionist method to evaluate tongue-tip placement of /s/ and /z/ sounds in American English, as it is the most prevalent method used in clinical practice. We also adopt their stated goal to raise 'awareness that using alternative articulation can produce acceptable sounds, could result in interventions that capitalise on such alternative placements and make language instruction more effective' (p. 396). Indeed, as the vast majority of clinics in Israel are not equipped with EPG systems (allowing an instrumental analysis), the impressionist approach can be easily followed in clinical practice, guiding intervention programmes. Finally, Karlsson et al. (2002) noted that 'there is good evidence for reliable differences in articulatory behaviours that may not be observable by auditory-perceptual and/or acoustic methods' (p.407). Thus, in Experiment 3, both an impressionist paradigm and acoustic analysis were used.

Following McLeod, Roberts, and Sita's (2006) recommendation, we evaluated production of naive typical speakers rather than that of students and SLPs. In Experiment 1, 100 participants produced Hebrew CVC words, with the target sibilants at the onset (initial) or coda (final) positions, and were asked to report their tongue-tip placements. We chose the CVC structure since we wanted to assess articulation patterns in real words that are reasonably frequent and familiar in Hebrew. In Experiment 2, a different sample of 102 participants produced a longer Hebrew word list, consisting of monosyllabic (CVC) as well as disyllabic words (CVC.CVC). This experiment was designed to evaluate speaker-related variables (tongue-thrust, ankyloglossia and gender) and stimulus-related variables (word length, sibilant location and coarticulation) that may affect tongue-tip placement. In Experiment 3, a new sample of 40 participants produced the sibilants in isolation, and acoustic data were collected and analysed.

### **Experiment 1: A preliminary study: Tongue-tip placement in sibilant production in Hebrew**

The present experiment is a preliminary investigation of initial clinical impressions that at least some Hebrew speakers produce the sibilants /s, z/ with a laminal tongue position, rather than an apical one (as was previously found in other languages).

#### **Method**

##### **Participants**

One hundred young adults (52 males; age range 20–38 years old,  $M = 24.8$ ,  $SD = 2.9$  years) participated in this experiment. An additional eight participants were excluded due to articulation disorders (five with a mild lisp, two with a moderate lisp, and one with a lateral sibilant articulation). They were Israeli university undergraduates or their peers and received either partial course credit or volunteered for the study. All participants were fluent and competent Hebrew speakers, either native speakers born in Israel ( $N = 87$ ) or bilinguals (heritage speakers) who immigrated to Israel before the age of four years and have been speaking Hebrew as their dominant language ever since. Their language level was assessed during a preliminary interview with a research assistant (RA), a trained SLP student with a background in clinical phonetics. None of the participants suffered from (a) abnormal oral structure or function, (b) phonetic (articulation) disorder, (c) hearing problems, (d) neurological disease, as confirmed by a questionnaire. In addition, (e) we excluded participants who acquired Hebrew after the age of four years to avoid possible biases (see, Ben-David, Avivi-Reich, & Schneider, 2016). The study was approved by the local ethics committee, and signed informed consent was obtained from each participant.

##### **Speech material**

Twelve CVC words were used in the experiment. Half of the words (6) included the sibilant /s/ and the other half the sibilant /z/, with various locations of the target sibilant, counterbalanced across words, for example, /bas/(bass) and /ziv/(splendor).



### **Procedure and analysis**

The participants were tested individually in a quiet room in the university's clinic. Upon arrival, each participant read and signed the informed consent form, and reported his/her demographic and health data on a questionnaire. Next, the participants were given a short explanation regarding articulation placements, and the RA demonstrated the place of articulation of the consonants /l, m, k/ (alveolar, bilabial and velar, respectively). Then, participants were given a set of six practice CVC words with the same consonants (/l, m, k/) at initial or final positions and were asked to read them aloud, focusing on the target consonant, and to report the places of articulation. Once the participants stated that they could determine the articulators' positions, the test phase began.

Our testing procedure followed previous studies (Raver-Lampman & Dossou, 2011; Starks, 2000; Tomlinson, Morse, Bernard, Greensmith, & Meara, 2007). Participants were given the word list printed on an A4 page (words were printed in a pseudo-random order). The RA asked them to read the words aloud, slightly sustaining the target consonant (/s/ or /z/), holding the tongue in its position. After each word, they were asked to report their tongue-tip placement. No feedback was given to the participants (on accuracy of production/reporting) throughout the study. However, in case, a participant was not sure (a total number of six participants), and he or she was asked to repeat the word, hold the target sibilant and slowly part the lips and teeth to show the tongue placement to the RA. The place of tongue-tip was coded by the RA. The whole session (including informed consent and debriefing) lasted approximately ten minutes.

### **Results and discussion**

Out of 100 participants, the majority (59 participants) reported producing /s/ and /z/ using laminal tongue placements, 23 reported apical placements, and the remaining 18 participants reported either laminal or apical positions across the study words, ( $\chi^2(2) = 30.02, p < .001$ ). None of the tested background variables (country of birth, age and gender) was found to have a significant effect on reported tongue-tip placement (non-significant  $\chi^2$  tests), and they will not be further discussed.

In sum, in this initial investigation, the majority of participants reported pronouncing the target sibilants in monosyllabic words with a laminal ('blade') point of constriction on the tongue. Such placement is different from the apical ('tip') placement that is commonly used by SLPs instructing Hebrew speakers. Note, as we did not anticipate such a large deviation from the expected high prevalence of apical placement, no other variables were assessed in this preliminary examination, nor did we fully control for adjacent vowels and second consonants. In order to substantiate this new finding and assess the role of speaker- and stimulus-related variables, the second experiment was conducted.

### **Experiment 2: The effect of speaker- and stimulus-related variables on tongue-tip placement in sibilant production in Hebrew**

The first goal of the present experiment was to verify the surprising results of Experiment 1, which showed that the majority of Hebrew speakers (60%) produce the sibilants /s, z/ with a laminal point of constriction on the tongue and not with the expected apical placement. The second goal was to evaluate the effect of speaker-related variables (tongue-thrust and



ankyloglossia) and stimulus-related variables (sibilant type, word length, sibilant location and coarticulation) on tongue-tip placement.

A similar procedure was used, but the word list was expanded to include disyllabic as well as monosyllabic words. This prompted an evaluation of possible effects of sibilant location and coarticulation. We hypothesised that an apical sibilant production will be more likely found with an adjacent alveolar consonant (e.g. /t, d, n/, as in the word /min.sa/, baby carrier) than with an adjacent non-alveolar consonant (e.g. /k, m/, as in the word /mak.sim/, charming), and vice versa. To evaluate speaker-related variables, participants were also assessed for possible ankyloglossia and for their swallowing patterns.

## Method

### Participants

A different sample of 102 young adults (61 females; age range 20–30 years old,  $M = 23.8$ ,  $SD = 2.8$  years) participated in the study. Inclusion and exclusion criteria were similar to these of Experiment 1. Six additional participants were excluded due to articulation disorders (five with a mild lisp, one with a moderate lisp).

### Speech material

Table 1 provides the list of 36 words used in this experiment, 12 monosyllabic (CVC) words and 24 disyllabic words (most of them CVC.CVC). Half of the words (18) included the sibilant /s/ and the other half the sibilant /z/, with various locations of the target sibilant, counterbalanced across words (onset or coda position, of the first or second syllable). In order to test possible co-articulation effects, the preceding or following consonants to the target sibilant were either alveolar (/n, l, d, t/, e.g. /min.sa/, /maz.leg/) or non-alveolar (dorsal /k, g, ʁ/, bilabial /m/, or labiodental /f/, e.g. /ʔaʁ.sal/, /maz.gan/, the translation of all words is presented in Table 1). The order of words was counterbalanced across participants.

**Table 1.** Word list for Experiment 2. English translations appear in parentheses.

Target sibilant	Monosyllabic words		Disyllabic words			
	Onset	Coda	Adjacent alveolar consonant		Adjacent non-alveolar consonant	
			Onset	Coda	Onset	Coda
/s/	sav (grandfather)	bas (bass)	min.sa (baby carrier)	kas.da (helmet)	ʔaʁ.sal (hammock)	mas.ʁek (comb)
	siʁ (pot)	gis (brother-in-law)	kat.sal (children's basketball)	ʔes.teʁ (Esther, name)	mak.sim (charming)	pas.kol (sound track)
	sof (end)	mus (mousse)	pal.saʁ (reconnaissance battalion)	mas.lul (path)	kuf.sa (box)	mas.meʁ (nail)
	zeʁ (bouquet)	baz (falcon)	min.zaʁ (monastery)	miz.non (snack bar)	ʁam.zor (traffic light)	maz.ʁek (syringe)
/z/	zol (cheap)	ʔoz (courage)	gin.zax (archives)	maz.leg (fork)	mag.zim (exaggerating)	maz.gan (air conditioner)
	zug (pair)	luz (hazelnut)	bal.za (ochroma)	maz.lat (UAV)	maʁ.ze (slimming)	ʔez.ʁa (help)

### Procedure and analysis

These were similar to Experiment 1, except for two differences. (1) the RA also evaluated possible ankyloglossia, by scoring the appearance of the tongue when lifted and by using the first three function items (lateralisation, lift and extension of tongue) of the Hazelbaker Assessment Tool for Lingual Frenulum Function (HATLFF; Amir, James, & Donath, 2006). All but a single participant were scored 'Perfect' to 'Acceptable', and thus, this variable will not be further discussed. (2) The RA also evaluated the swallowing patterns of the participants, in order to recognise patients with abnormal patterns (mainly tongue-thrust – 'reverse' or 'immature' swallow). Participants were asked to swallow 5 ml of water. Following a 10 Sec rest period, they were asked to swallow once more without water (an empty swallow). Swallowing patterns were confirmed using traditional lip retracted inspection during saliva swallowing (Peng, Jost-Brinkmann, Yoshida, Miethke, & Lin, 2003). Tongue thrust severity in swallowing was scored using a three-point scale (Christensen & Hanson, 1981). Seventy-seven participants showed a mature swallowing pattern, 20 participants showed a mild tongue-thrust swallowing pattern, and only five showed a moderate tongue-thrust swallowing pattern (none of the participants showed a severe tongue-thrust swallowing pattern). Note, a total number of five participants were not sure whether they used an apical or a laminal tongue-tip placement, so they were assisted by the RA, in a similar manner to that described in Experiment 1.

### Results and discussion

As a first step, to replicate Experiment 1, we tested monosyllabic words. A repeated measures ANOVA was conducted, with the type of sibilant (/s, z/) and the location (onset, coda) as within-participant factors, and gender and tongue-thrust as between-participants variables. A main effect was found for the type of sibilant, where the chances of laminal placement were higher for /s/ than for /z/ (66.2 vs. 58.7%, respectively;  $F(1,98) = 5.7, p = .02, \eta_p^2 = .06$ ). No main effects were found for sibilant location, nor for the between-participants variables, gender and tongue-thrust swallowing ( $p > .18$ , for all). No significant interactions of the latter variables with any of the within-participant variables were found ( $p > .12$ , for all). Overall, sibilants were more likely produced with laminal tongue-tip placement than an apical one,  $t(101) = 3.7, p < .001$ .

In the next step, we focused on disyllabic words (the most common word size of Hebrew stems; Adam & Bat El, 2008). We conducted a repeated measures ANOVA with type of sibilant (/s, z/), location (onset, coda), and adjacent-consonant (alveolar, non-alveolar) as within-participant factors and gender and tongue-thrust as between-participants variables. All three main within-participant effects were found to be significant, indicating higher chances for laminal tongue-tip position in (a) /s/ than /z/ (58 vs. 52%;  $F(1,99) = 5.99, p = .016, \eta_p^2 = .06$ ); (b) coda than onset (58 vs. 53%;  $F(1,99) = 6.37, p = .013, \eta_p^2 = .06$ ); and (c) non-alveolar than alveolar adjacent consonant (57 vs. 53%;  $F(1,99) = 5.58, p = .02, \eta_p^2 = .05$ ). No two-, three-, four- or five-way significant interactions were found. We also note that for disyllabic words (similar to the results with monosyllabic words), the overall chances for laminal tongue-tip placement were higher than for the apical one ( $t(101) = 2.29, p = .02$ ). Gender and tongue-thrust presence did not have a significant effect and will not be further discussed.

Taking both mono- and disyllabic words together, the chances of the laminal tongue-tip position were found to be higher for monosyllabic words (62.8 % vs. 58.2%,  $t(101) = 3.15$ ,

$p = .002$ ), across word types and sibilant locations. Finally, from a clinical standpoint, it is important to note that the chances of a laminal production in one sibilant (across all conditions) were highly correlated with the chances of a laminal production in the other sibilant,  $r_p(102) = .81$ ,  $p < .001$ . That is, individuals who were more likely to produce one sibilant in a specific point of constriction on the tongue (either laminal or apical) were also more likely to produce the other sibilant in the same placement,  $\chi^2(4) = 89.2$ ,  $p < .001$ , with 78% of participants showing this pattern (full data are presented in the Appendix, available in the online supplementary files).

### Experiment 3: Acoustic analysis of Hebrew sibilants

Experiments 1 and 2 showed that both the *laminal* point of constriction on the tongue and the apical tongue-tip position are commonly used by young adult Hebrew speakers producing /s, z/, with the laminal more frequent than the apical. This evidence offers SLPs valuable information for articulation therapy. Together, the experiments suggest that SLPs do not need to restrict their articulation guidelines to one tongue-tip placement, but rather should provide the client with the phonetic placement instructions that suit individual abilities and preferences.

The literature suggests that the two placements are acceptable in English production as well (Stone et al., 2012) and do not differ acoustically or perceptually (Karlsson et al., 2002; Stoner, Gateley, & Rivers, 1987). However, it is possible that although the two variants of /s/ and /z/ production (apical and laminal) are acceptable in Hebrew, they may still differ acoustically. The main goal of Experiment 3 was to test possible acoustic differences between these two variants for Hebrew speakers.

The secondary goal of Experiment 3 was to test whether the pattern of tongue-tip placements noted in Experiment 1 (for monosyllabic words) and Experiment 2 (for mono- and disyllabic words) would be replicated when the sibilants were produced in isolation, with no possible coarticulatory or semantic effects (Ben-David, Moral, Namasivayam, Erel, & Van Lieshout, 2016; Van Lieshout, Ben-David, Lipski, & Namasivayam, 2014). Notice, the location of the spectral peaks in the friction noise is vowel dependent (Soli, 1981). Thus, focusing on the production of the sibilant in isolation provides a 'cleaner' picture.

## Method

### Participants

A new sample of 40 young adults (20 males; age range 20–30 years old,  $M = 24.9$ ,  $SD = 2.6$  years) participated in this experiment. They all were Israeli university undergraduates who volunteered for the study. Inclusion and exclusion criteria were similar to those of Experiment 1.

### Speech material

Participants were asked to produce the two sibilants in isolation (in a random order), for 2 sec each (following, Nozaki et al., 2014; Schwartz, 1968). These simple stimuli minimise possible coarticulatory effects and facilitate acoustic analysis.

### **Procedure and analysis**

Participants were recorded individually in a quiet room in the lab. First, the participants were given a short explanation regarding articulation placements (similar to Experiment 1) and verified that they could determine their tongue-tip position. Following this, participants were asked to produce /s/ and /z/ (order of sibilants was random) for 2 sec each and to report their tongue-tip placements. The place of the tongue-tip was coded by the RA. No feedback was given to the participants (on accuracy of production/reporting) throughout the study. Recordings were made using a high-quality portable digital recorder (Olympus Europa SE & CO. KG; VN-8500PC). The recorder was tilted toward the speaker and was positioned about 6 cm from the speaker's nose and approximately 5 cm from the corner of the speaker's mouth (to prevent turbulence due to direct airflow from impinging on the microphone).

Our recordings were analysed for the following parameters: (a) intensity (amplitude, dB) and (b) centre of gravity (measuring the frequency characteristics of the friction noise, Hz). For each token, these parameters were examined at the midpoint of the friction noise. These parameters were chosen following findings by Jongman, Wayland, and Wong (2000) that spectral and amplitudinal features provide the most critical information to place of articulation in fricatives. The analyses were performed using Praat software (Boersma & Weenink, 2017).

### **Results and discussion**

Out of 40 participants, the majority (26 participants, 65%) reported producing /s/ and /z/ using laminal tongue placements, six (15%) reported apical placements for both sibilants, and the remaining eight participants (20%) reported either laminal or apical positions across the sibilants,  $\chi^2(1) = 9.6, p = .002$ . Gender was not found to have a significant effect on reported tongue-tip placement, for either /z/ or /s/ (non-significant  $\chi^2$  tests).

Table 2 presents the acoustic data separately for apical and laminal reported placements for /s/ and /z/. To analyse the acoustic data, we conducted separate MANOVAs for /s/ and for /z/, with laminal or apical tongue placements as a between-participants variable, gender as a covariate (to remove variance related to gender differences in acoustic characteristics; see Flipsen et al., 1999), with the following dependent variables: minimal intensity (dB), maximal intensity (dB) and centre of gravity (Hz). In the analyses for /s/ and for /z/, tongue-tip placement was not found to have a significant effect on either of the dependent variables,  $F(1,37) \leq 3.1, p \geq .09$ , nor did gender,  $F(1,37) \leq 2.2, p \geq .14$ .

In sum, in our sample of Hebrew speakers, tongue-tip placement (laminal or apical) did not change the acoustical features of /s/ and of /z/ productions significantly. These results are in line with evidence in the literature on the weak relationship between the acoustic waveform (i.e. distinct spectral patterns) and phonetic features (e.g. place and manner of articulation; Jongman et al., 2000). Since the speech signal is characterised with high variability, the correspondence between acoustic cues and phonetic perceptions is typically low. Our data expand this literature as, hitherto, fricatives received relatively little attention.

**Table 2.** Mean (and SDs, in parentheses) values of amplitude (min. and max, in dB), and centre of gravity (in Hz), for each sibilant (/s, z/) for the apical and laminal places of articulation (averaged across gender), in Experiment 3.

Sibilant	Place of articulation	Minimum amplitude (dB)	Maximum amplitude (dB)	Centre of gravity (Hz)
/s/	Apical	56.83 (4.73)	74.06 (6.32)	7902.37 (2040.93)
	Laminal	58.73 (5.24)	74.41 (5.72)	7811.04 (1160.72)
/z/	Apical	57.33 (5.05)	71.19 (1.92)	2643.14 (1609.28)
	Laminal	60.80 (4.78)	73.81 (3.57)	2027.04 (1903.20)

## General discussion

Logopedic treatment of sibilants production usually consists of learning the correct place of articulation (Brunner, Hoole, & Perrier, 2011). Such precise articulatory placement is required for the correct production of /s, z/, as the tongue forms a narrow constriction in the alveolar region of the palate and the airstream is directed towards the incisors. For English speakers, these sibilants can be produced using (at least) two different, and quite prevalent, tongue positions: (a) apical – using the tongue-tip to contact the alveolar ridge or (b) laminal – using the tongue blade (Dart, 1991; Stone et al., 2012).

However, the ‘correct place’ of the tongue-tip during /s, z/ production in Hebrew is not clear, which may be detrimental to speech therapy. Textbooks (e.g. Hebrew IPA charts; Laufer, 1999) describe the place of articulation as alveolar, but do not specify the point of constriction on the tongue – apical (tip) or laminal (blade). In articulation therapy, most SLPs use the apical variant, with the tongue-tip raised towards the upper ridge (e.g. Ladefoged, 1993). Clinical observations suggest that many individuals produce the sibilants with a laminal tongue-tip placement. Such uncertainty may impair clinical interventions, delaying the successful acquisition of correct sibilant articulation (for a similar variability in Israeli Hebrew rhotics’ production, see Cohen, 2015). The first goal of the current study was to determine which tongue-tip position is most frequently used by adult Hebrew speakers in order to produce the sibilants /s, z/, apical (upper position) or laminal (lower position). In Experiment 1, 100 participants reported the tongue-tip placement during /s, z/ productions in monosyllabic words. This initial investigation shows that most adult Hebrew speakers (60 %) report a *laminal* tongue-tip position. Findings were confirmed in Experiments 2 and 3, with different sets of participants ( $n = 142$ ) and different stimuli. We conclude that for the majority of Hebrew speakers, the laminal tongue-tip placement is more common than is the apical one. Interestingly, gender was not found to affect the tongue-tip placement, nor other speaker-related factors (tongue-thrust, ankyloglossia).

The second goal of the study was to evaluate the effect of stimulus-related variables on sibilant tongue-tip placement. Participants reported their tongue-tip placement during the sibilant production in isolation, in mono- as well as in disyllabic words, varying both the location of the sibilant and the type of adjacent consonant. We found several phonological features that increased the likelihood of the laminal placement: the sibilant /s/, monosyllabic words, coda position and non-alveolar adjacent consonants. Moreover, it appears that participants who were more likely to produce one sibilant in one place of articulation

were also more likely to produce the other sibilant in the same placement. Experiment 3 confirmed the absence of acoustic differences (minimal and maximal intensity and centre of gravity) between the apical and the laminal sibilants in Hebrew.

These results have clinical implications for the treatment of the common sibilant articulation impairments in Hebrew. In particular, as in spoken Hebrew, the sibilants are more marked (characterised by articulatory and perceptual difficulty; Adi-Bensaid & Ben-David, 2010), thus late in acquisition (Ben-David, 2015).

### ***Most Hebrew speakers produce sibilants with a laminal (rather than apical) tongue placement***

Across Experiments 1, 2 and 3, the prevalence of a laminal production of sibilants for adult Hebrew speakers was about 60%, significantly higher than the apical one (across gender), which was traditionally considered the most frequently used in Hebrew. These results support previous studies, suggesting that there might be wide variation in tongue placement for the production of perceptually normal /s/ and /z/ across languages (e.g. McLeod et al., 2006; Roberts, McLeod, & Sita, 2002).

Identifying these acceptable tongue-tip placements is important in planning intervention programmes for people with articulation difficulties. In order to assist a patient to produce a correct /s/ sound easily, it is important to identify these variations of tongue-tip location. In English, there is no known determinant for a speaker's use of the apical /s/ versus the laminal one (Stone et al., 2012). Our findings suggest a similar pattern in Hebrew as well. From a clinical perspective, it is the ease and comfort of articulation, according to the client's self-report, which should guide the SLP, rather than adherence to the Hebrew IPA chart. This suggested guideline may assist the SLP in choosing the target tongue-tip placement in therapy.

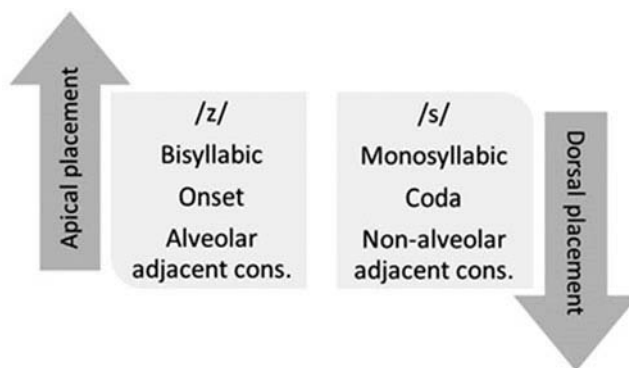
According to Shriberg (2009), many articulation errors involve the distortion of sibilants. Residual articulation disorders are prevalent among young adults. For example, Van Borsel et al. (2007) found a high prevalence of lispings (23%) among young Dutch-speaking adults. Treatment of such articulation problems should focus on learning to refine the phonetic productions, gradually achieving phonetically accurate speech (Preston et al., 2012; Shriberg, 1994; Shriberg et al., 2005). Many 'classic' therapy procedures are based on the SLP producing a model of the target sound in isolation, followed by the patient's attempts to correctly produce the target sound (Rogers & Chesin, 2013). However, currently Hebrew speakers' SLPs demonstrate sibilant production using the apical placement. Our results suggest that this production is less commonly used in Hebrew than is the laminal one, and guidelines should be reconsidered. SLPs should be aware of the different tongue-tip placements and be able to produce an appropriate model, according to the abilities of each Hebrew-speaking client, applying a client-centred practice (Sumsion & Law, 2006). This will allow for a better selection of therapy goals for sibilants' mis-articulations – as the SLP explains and models the apical placement or the laminal placement, which appears to be more frequent among young Hebrew speakers. The client can practice both placements and choose the most comfortable, easy-to-produce variant. This is of special interest, as our data suggest that the variants do not change the acoustics of the sibilants.

### **Stimulus-related variables that affect sibilant production**

The second goal of this study was to investigate whether coarticulation affects tongue-tip position at sibilant production. The literature points to articulatory differences in the production of the same sounds based on their position in the word (Byrd, 1996; Krakow, 1999) and surrounding phonemes (Lotto & Kluender, 1998. For relevant findings on prosodic effects on segmental acquisition in Hebrew, see Cohen, 2015). However, Tabain (2001) claimed that sibilant fricatives may have some coarticulatory resistance and are less influenced by these factors than other phonemes. The current study is the first to test if these variables have a significant effect on sibilant production in Hebrew. As expected, an adjacent alveolar consonant was more likely to result in an apical position of the sibilant, whereas an adjacent non-alveolar consonant lowered the tongue-tip at the sibilant production, leading to a laminal position. Moreover, the laminal tongue-tip placement was especially evident in the following conditions: (a) monosyllabic words and (b) coda position. Hence, from a clinical perspective, we recommend using such stimuli in therapy (whether real or non-words; Ben-David & Icht, 2017; Icht & Ben-David, 2015; McLeod et al., 2006), in order to practice the laminal tongue-tip placement in the easiest and most convenient context (for a related recent investigation on the clinical implications of allophonic variation of the Hebrew rhotic /ʁ/, see Cohen & Ben-David, 2016).

However, for those clients who report that the apical tongue-tip placement for sibilants' production is more comfortable and easy, we would recommend using different stimuli, namely (a) /z/ sound, (b) disyllabic words, (c) onset position and (d) alveolar adjacent consonant. Words that follow these criteria will easily allow an apical tongue-tip placement. Visual description of these recommendations is provided in Figure 1. Importantly, note that the Hebrew stridents are acquired in coda position before onset position (Ben-David, 2001). Proper selection of target stimuli in therapy should also consider this prosodic pattern.

Our results also revealed some differences between /s/ and /z/ production, as laminal production was more frequently used with /s/ than with /z/. Usually, these sibilants are grouped together, described as having similar placement for production (Bauman-Wangler, 2000; Laufer, 1999). However, differences between these consonants have already been reported in the literature. For example, Dart (1998) investigated the difference in the production of the coronal consonants /t, d, n, l, s, z/ between French and English speakers.



**Figure 1.** Clinical recommendations for target selection based on the current results.



The author found high levels of individual variation in both languages, both between speakers and between consonants. She concluded that speakers within a specific language do not all produce these consonants at the same place of articulation, in accordance with our results (see Appendix).

Interestingly, some EPG studies conducted with English speakers identified differences in articulation between the sibilants, namely greater tongue-palate contact for /z/ compared to /s/ (Dagenais, Lorendo, & McCutcheon, 1994; McLeod et al., 2006). The current results (in Hebrew) support these findings, since we documented more apical tongue-tip placement for /z/, and such placement results in greater tongue-palate contact (compared to the laminal production).

A possible cause for the differences in articulatory patterns may stem from the different laryngeal activities related to /s/ and /z/. The /z/ sound requires a tongue-tip constriction, while the vocal folds remain adducted for voicing. However, /s/ requires both a tongue-tip constriction, and laryngeal abduction for devoicing. Interestingly, airflow rises with vocal folds abduction and decreases with tongue-tip constriction. The combination of (a) precise supraglottal constriction, (b) abduction for devoicing and (c) high airflow, in /s/, may yield an added level of complexity compared to /z/ (Koenig, Lucero, & Perlman, 2008). Indeed, Koenig et al. found that variability in airflow (represented by the amplitude index) was higher for /s/ than for /z/, highlighting the relative complexity of the combination of the three aforementioned /s/ characteristics. This difference in articulatory complexity between /s/ and /z/ may explain the differences in tongue-tip placements between the two, as found in our data.

### ***Clinical recommendations***

The main finding of the current study is the high prevalence of the laminal point of constriction on the tongue in sibilant production among adult Hebrew speakers. We suggest that SLPs treating Hebrew-speaking patients be aware of the variability in tongue-tip placements. Interventions should assess which production (apical or laminal) is more appropriate to an individual speaker. In other words, a trained SLP would be advised to produce an appropriate model, according to the abilities of each client. This is of special importance, as it appears that speakers use a consistent tongue-tip position across sibilants and sibilant locations in the word.

The current study also identified several stimulus-related variables that can affect sibilant tongue-tip placement. Designing a client-centred intervention, the SLP should be able to choose the appropriate target words (or non-words, see Ben-David & Icht, 2017; Icht & Ben-David, 2015; McLeod et al., 2006) that will facilitate an apical or a laminal production of sibilants. [Figure 1](#) presents a visual summary of our findings and recommendations for target selection.

### ***Caveats and future studies***

The present study used self-reports to estimate tongue-tip placement at sibilant production. Indeed, self-reports may be less accurate than physiological measures, such as EPG. However, self-reports are easy to administer, cost-effective and non-invasive. As noted by Dart (1998), ‘Tongue contact patterns can, after all, be felt with minimal introspection by

any speaker and we are accustomed to labelling consonants in this way' (p. 93). In order to overcome possible inaccuracies, a large sample (over 240 participants) was recruited for the current study. Moreover, the same pattern of results was obtained (higher frequency of laminal production) in three different samples. To verify that participants could accurately follow instructions, a detailed protocol was administered by a trained SLP student. Future studies may wish to further validate the current findings using EPG or other objective-instrumental measurements.

We note that our target words were not fully controlled for adjacent consonants and vowels (before or after the sibilant) or for stress. In addition, although we targeted relatively frequent and familiar Hebrew words, some were less familiar than others (e.g. *bal.za*). To partially overcome these possible biases, we used a relatively long list of words in Experiment 2 (36 words), which were not used in Experiment 1. Additionally, in Experiment 3 sibilants were tested in isolation, to avoid possible semantic effects (for discussions, see Algom, Chajut & Lev, 2004; Ben-David, Chajut & Algom, 2012). Our main finding was confirmed across the three experiments, with different sets of stimuli and participant samples. Namely, two points of constriction on the tongue are common for sibilant production in Hebrew – apical (tip) or laminal (blade). Future studies may use fully controlled word lists, showing possible effects of adjacent consonants and vowels.

We also note that the study goals were not concealed from participants, allowing for a possible bias in responses. Yet, we believe that the pattern of results suggests otherwise. First, as no feedback was given to participants on accuracy of production (or reporting), we can assume that their productions reflect their habitual articulation. Second, in Experiment 2, tongue-tip placement was found to be affected by the location of the sibilant in the syllable (coda vs. onset) and by the adjacent consonant (alveolar vs. non-alveolar). If participants were attempting to produce the sibilant in the same manner every time, these effects would not have been as evident. Finally, the same pattern (about 60% laminal production) was noted across three experiments with different samples and different stimuli.

In the current study, speaker-related variables, such as tongue-thrust swallowing and ankyloglossia, did not significantly impact the results. This is probably due to the relatively small number of participants who showed such characteristics. Future studies may wish to focus on these unique populations and further examine their articulatory patterns. Finally, since the tongue-tip location in sibilant production is unclear and unspecified in many languages (e.g. Japanese; Nozaki et al., 2014), more research in various languages is called for (noting that sibilant production is language/dialect sensitive), providing better clinical guidelines for SLPs (for related evidence regarding cross-language variation in the oral-DDK task norms, see: Icht & Ben-David, 2014).

## Declaration of interest

The authors report no conflicts of interest.

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