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Original Article

Artigo Original

A comparison of vocal parameters in adult bilingual Hebrew-English speakers

Comparação de parâmetros vocais em adultos bilíngues falantes de Hebraico e Inglês

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ABSTRACT

Purpose: There has been growing research on the effects of language on voice characteristics; however, few studies have examined the impact of language on vocal features within bilinguals. This study aimed to compare vocal parameters among bilingual Hebrew/English speaking individuals when speaking in Hebrew versus English. **Methods:** Forty bilingual participants (17 males and 23 females) between the ages of 23–60 years were asked to spontaneously speak about a neutral topic. Voice samples were digitalized into a tablet for perceptual and acoustic analyses of selected parameters. **Results:** Results show that there are changes in resonance, glottal attack, fundamental frequency variation and speech rate when adult bilingual speakers talk in Hebrew as compared to English. **Conclusion:** These findings provide evidence that language plays a role in affecting vocal characteristics of bilingual individuals when they speak different languages.

RESUMO

Objetivo: Muitas pesquisas foram realizadas para investigar o efeito da língua-mãe em características vocais. Contudo, poucos estudos investigaram o impacto da língua-mãe em características vocais de indivíduos bilíngues. O presente estudo teve como objetivo comparar parâmetros vocais de indivíduos bilíngues que falam Hebraico e Inglês ao falarem Hebraico versus Inglês. **Métodos:** Participaram desta pesquisa 40 indivíduos bilíngues em Hebraico e Inglês, 17 do gênero masculino e 23 do gênero feminino, com idade variando de 23 a 60 anos. Os participantes foram instruídos a discursar espontaneamente sobre um tópico neutro. As amostras foram digitalizadas diretamente em um tablet para análise perceptivo-auditiva e acústica de parâmetros selecionados. **Resultados:** Os resultados mostraram que há diferenças na ressonância, ataque vocal, variabilidade da frequência fundamental e velocidade de fala quando os indivíduos bilíngues falam Inglês e Hebraico. **Conclusão:** Esses achados mostram evidências de que a língua-mãe influencia as características vocais dos indivíduos bilíngues quando falam diferentes línguas.

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INTRODUCTION

Although the physiological production of voice is essentially universal, the characteristics of voice are varied and dynamic across human speakers. Gender, age and weight are among the factors that are most reported to influence the vocal characteristics of an individual[1-5]. In order to better understand the heterogeneous nature of voice, researchers should consider other factors that may contribute to differences in vocal features among individuals, such as language impact.

There has been growing research on the effects of language on voice characteristics[6-21]. When listeners were asked to discriminate whether two speech samples were produced by the same bilingual speaker, listeners were less accurate in their judgment when the speaker switched between English and Finnish, English and German and English and Mandarin as compared to matched-language samples (e.g. English-English, Finnish-Finnish)[6]. This supports the hypothesis that language plays a role in changing vocal features. In addition to the linguistic factors that influence voice characteristics, such as segmental and supra-segmental properties, anatomical differences related to race/ethnicity and socio-cultural norms that are both closely related to one's language are suggested to result in characteristic variations as well[7-18].

The influence of culture on voice was explored in populations who spoke the same language, but differed in their cultural or ethnic backgrounds. Following voice analysis, research conclusions indicated differences in vocal parameters between cultural populations, particularly in fundamental frequency (F0) and perturbation measures, which confirms the role of sociocultural elements in the varying measures of voice output[19-21]. Cross-population studies that have looked at the effect of language on vocal features have also discovered differences, primarily in mean F0 and fundamental frequency range. While a cross-language comparison of mean F0 in languages such as Dutch and Japanese attributed the varying acoustical voice measures to cultural norms[8,10], others have related these findings to differences in linguistic and phonological systems, such as in the comparison of tonal and stress languages (i.e. Mandarin and English, respectively) or English and German[11-14]. However, by comparing vocal features in different speakers, researchers neglected to control for inherent variables among these speakers, such as personality, anatomical and other inter-individual differences.

One possible way to control for these variables is to examine the influence of language on voice among bilinguals. Examining changes in a speaker's voice, when the same individual produces one language and then another, will lead to improved validity in results and better isolate language as a factor in voice output. Few studies in the literature examine the impact of language on voice characteristics within bilinguals. Overall, existing research on bilingual speakers of Russian/English, German/English, Catalan/Spanish and Cantonese/English has revealed a difference in acoustic vocal parameters, particularly in mean F0 and F0 range, when comparing the speaker's voice output in each language[9,14-18].

Based on these conclusions, it is important to extend research to other languages as well. The study's objective was to compare select vocal parameters among bilingual Hebrew-English speaking individuals when speaking in Hebrew versus in English. While other studies have exclusively analyzed acoustic voice measurements, this study aimed to perform a combination of acoustic and perceptual analyses on automatic connected and spontaneous speech samples. These speech tasks were used for analysis, since reading tasks (e.g. a selected reading passage) may not reflect the subject's true vocal nature in conversation[9,22]. Perceptual analysis of bilinguals' voices will corroborate anecdotal evidence that people can perceive differences in voice characteristics when individuals switch between fluent languages.

Previous studies have looked at a more restricted age range, such as children, young adults, and the elderly. The current study examine individuals in their young and middle adulthood, between the ages of 23–60, at which point voice is reported to have stabilized[23]. The researchers hypothesize that there are changes in select vocal parameters when adult bilingual Hebrew speakers talk in Hebrew as compared to English, following both acoustic and perceptual analyses. A more specific prediction is that females will demonstrate with an increased mean F0, or pitch, when speaking in Hebrew compared to English and that males will demonstrate with a lower mean F0, or pitch, when speaking in Hebrew versus English.

METHODS

Participants

Forty bilingual Hebrew/English speakers, including 17 males and 23 females between the ages from 23 to 60 (mean: 43.625), participated in the study. All participants were judged to be fluent in Hebrew and Standard American English. Fluency was determined by the participants' ability to coherently speak the language in lengthy conversations with few pauses and in a wide variety of contexts[24]. They were recruited from the Brooklyn, NY, area and lived in the United States for an average of 30.07 years at the time of recording, the minimum being 11 years. Individuals were excluded from the study if they reported any known hearing deficits, voice, speech or language disorder, or if they were judged to be insufficiently fluent in either Hebrew or English. Additionally, at the time of recording, none of the participants exhibited any cold-like symptoms or upper respiratory problems. They were pre-screened for these conditions in order to preclude any variable that can interfere with the validity of the results. All participants signed an Informed Consent approved by the Touro College, School of Health Science Institutional Review Board (#1337).

Procedures

Voices were recorded in a quiet room, using an iRig unidirectional microphone and an iRig recording app on the iPad as an audio recording device[25]. First, the participants were recorded while sustaining a vowel for about 10 s. Then, automatic

speech samples were acquired when the participants counted from one to ten in both Hebrew and English. These samples were collected in order to obtain baseline data of their voice quality. Finally, each participant was asked to spontaneously answer an open-ended question on a neutral topic (i.e. describe today's weather), in both Hebrew and English, at a comfortable pitch and loudness. Spontaneous connected speech samples were obtained to reflect the participants' true vocal nature when speaking in both languages.

Perceptual analysis

Speech samples were analyzed blindly by a Speech-Language Pathologist trained in the area of voice with a voice rating protocol developed for the purpose of this research. A total of 160 randomized samples were analyzed (40 automatic counting and 40 spontaneous speech Hebrew samples, 40 automatic counting and 40 spontaneous speech English samples). Intra-rater reliability was established using Kappa reliability measurements of the judge's re-test of 20 randomized samples (ten Hebrew samples and ten English samples). The intra-rater analysis yielded a Kappa measure of 0.789 ($p<0.001$), indicating substantial intra-rater agreement. The parameters selected for analysis were voice quality, pitch, resonance and rate in the recordings. Voice quality was assessed in regards to presence or absence of vocal roughness, breathiness, strain and vocal fry. These characteristics were marked on a 0–4 rating scale, with 0 indicating absence and any other rating indicating a presence of the vocal characteristic. Other voice characteristics were rated on a nominal scale, more specifically, glottal attack was characterized as adequate, soft, or hard; pitch was rated as either adequate, low or high; resonance was rated as adequate, nasal, oral or throaty; and rate was rated as either adequate, slow, or fast.

Acoustic analysis

The voice recordings were acoustically analyzed using PRAAT Software to obtain measurements of select vocal parameters, including mean F0, F0 variation, pauses per minute and words per minute (rate of speech). The duration of each speech sample was calculated, with the total mean duration of Hebrew samples measured at 7.8 s (7.5 for females; 8.3 for males) and total mean duration of English samples measured at 7.9 s (7.7 for females; 8.0 for males), and used to calculate the pauses per minute in the speech samples, indicating the amount of voice breaks in the sample as well as words per minute indicating the participants' rate of speech. F0 variation measures were obtained through subtracting maximum and minimum F0 ranges indicated in the PRAAT analysis.

Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) software, version 22 (SPSS Inc., Chicago, IL, USA). The data from the perceptual ratings of Hebrew and English samples were compared by using the Wilcoxon signed ranks test for non-parametrical variables. The test analyzed both language samples for statistically significant differences in pitch, resonance, rate (duration of the first 20 words), and overall voice quality during automatic counting and spontaneous speech tasks. The means of the acoustic parameters were then obtained for the total population, males and females and were compared in both language tasks using paired samples Student's t-test for parametrical variables. The Pearson and Spearman correlation tests were used for checking correlations of parametric and non-parametric variables, respectively.

RESULTS

Perceptual analysis

Results of the Wilcoxon signed ranks test for non-parametrical variables revealed significant changes in perceptual voice characteristics of the population during tasks of connected counting and spontaneous speech in Hebrew and English (Tables 1 and 2). Specifically, in the counting task, the total bilingual Hebrew/English population demonstrated significant differences in glottal attack ($p=0.029$). While 45% of the total population was judged as having hard glottal attack in their Hebrew counting samples, 67.5% of the same group exhibited hard glottal attack while counting in English. Additionally, females exhibited a statistical tendency towards glottal attack changes in Hebrew versus English counting ($p=0.083$). In Hebrew, 39.1% of females exhibited hard glottal attack compared to 65.2% of the same female group that were judged to have a hard glottal attack when counting in English (Table 1).

Significant changes in rate were revealed for the total population ($p=0.002$), females ($p=0.007$) and a statistical tendency was indicated for males: $p=0.083$ during the counting tasks. Of the total population, 65% demonstrated adequate rate in Hebrew compared to 92.5% when the group counted in English. Twenty-five percent of the total population was judged as having a fast rate while counting in Hebrew compared to 7.5% of the sample when counting in English. Ten percent of the Hebrew counting samples was characterized as having a slow rate, while none of the English samples were rated as slow. Amongst the female population, 56.5% were judged to have an adequate rate during the Hebrew counting task in contrast to 91.3% of the female sample when counting in English. Changes in rate were further demonstrated when comparing 31.9% of females who were judged as having a fast rate when counting in Hebrew to 8.6% of the females who were observed as having fast rate in English counting. Slow rate was detected in 4.3% of the female population while counting in Hebrew and was absent in the English counting samples.

It is also interesting to note that 2.5% of the total population and 4.3% of females were noted as having a nasal resonance while counting in English, while no nasal resonance was detected in Hebrew samples (Table 1). A tendency for males to exhibit changes in rate when counting in Hebrew compared to English was demonstrated as well ($p=0.083$). When judging the Hebrew counting samples, 76.4% of males were characterized as having adequate rate compared to 94.1% in English counting. Also, 17.6% of males were judged as having slow rate in Hebrew counting compared to an absence of slow rate while

counting in English. Additional significant changes found in the male population were in areas of resonance (p=0.046) and roughness (p=0.008); 58.8% were judged to have an adequate resonance while counting in Hebrew compared to 35.2% in English. A throaty resonance was rated in 41.1% of the male population while counting in Hebrew versus 61.7% in English. As mentioned earlier, roughness significantly varied when comparing male speakers counting in Hebrew and English. In Hebrew samples, 58.7% of males were judged as having a rough vocal quality during counting compared to 88.2% of the male sample in English counting (Table 1). In the spontaneous speech samples, adult Hebrew/English bilingual speakers demonstrated changes in resonance, glottal attack and vocal fry when comparing both language samples (Table 2). More specifically, statistically significant changes in resonance were found amongst the total population (p=0.005) and the female sample (p=0.013). Ninety percent of the total population was identified as having a throaty resonance when speaking spontaneously in Hebrew compared to 60% of the same population when speaking in English. Amongst the female group, 91.3% were characterized as having a throaty resonance while speaking in Hebrew compared to 52.1% of the same sample when speaking in English.

There was a greater incidence of hard glottal attack in English than in Hebrew during spontaneous speech for the total population (p=0.057). Fifty percent of the total population was judged to have hard glottal attack in Hebrew in comparison to 77.5% in English. Vocal fry was also indicated as having a higher incidence in English than in Hebrew for the total population (p=0.005) and in males (p=0.025), while females had a significant tendency to produce vocal fry in English compared to in Hebrew (p=0.083). The presence of vocal fry was absent in all spontaneous speech Hebrew samples compared to 20% of the total population, 29.4% of males and 13% of females that were judged to exhibit vocal fry during spontaneous English speech. No significant changes were noted when comparing overall vocal quality, pitch and rate in adult bilingual Hebrew/English speakers when speaking spontaneously in Hebrew versus English (Table 2).

Correlation testing of perceptual vocal parameters, including roughness, breathiness, strain, vocal fry, glottal attack, pitch, resonance and rate, was analyzed using Spearman's correlation for non-parametric variables to determine the strength of a monotonic relationship with the age the participants arrived in the USA. For the male population, a moderate negative correlation was found within the spontaneous speech Hebrew samples in relation to roughness (r=-0.525, p=0.031), reflecting a decreased association with roughness while speaking Hebrew for those who arrived later in the USA. For the female population, significant correlations were found in the counting samples that indicated a moderate positive relationship between the age participants arrived in the USA and the perception of vocal strain in Hebrew counting samples (r=0.469, p=0.032) and a moderate negative relationship for the two variables in English counting samples (r=-0.456, p=0.038). This reflects a likely relationship of: the older the female participant was when arriving at the USA, the greater the detection of vocal strain was while counting in Hebrew, while the perception of vocal strain

Table 1. Wilcoxon signed ranks test values for non-parametric perceptual variables (connected counting speech task)

Connected speech	Male					Female					Total				
	English		Hebrew		p-value	English		Hebrew		p-value	English		Hebrew		p-value
Parameters	n	%	n	%		n	%	n	%		n	%	n	%	
Vocal quality															
Roughness	15	88.2	10	58.7	0.008	3	13	7	30.4	0.102	18	45	17	42.5	0.405
Breathiness	3	17.6	3	17.6	>0.999	7	30.3	6	26	0.564	10	25	9	22.5	0.705
Strain	0	0	0	0	>0.999	3	13	2	8.6	0.655	3	7.5	2	5	0.655
Extra characteristic															
Vocal fry	0	0	0	0	>0.999	0	0	1	4.3	0.317	0	0	1	2.5	0.317
Glottal attack															
Adequate	5	29.4	8	47		8	34.7	14	60.8		13	32.5	22	55	
Soft	0	0	0	0	0.180	0	0	0	0	0.083	0	0	0	0	0.029
Hard	12	70.5	9	52.9		15	65.2	9	39.1		27	67.5	18	45	
No initial vowel	0	0	0	0		0	0	0	0		0	0	0	0	
Pitch															
Adequate	17	100	17	100		23	100	23	100		40	100	40	100	
Low	0	0	0	0	>0.999	0	0	0	0	>0.999	0	0	0	0	>0.999
High	0	0	0	0		0	0	0	0		0	0	0	0	
Resonance															
Adequate	6	35.2	10	58.8		18	78.2	16	69.5		24	60	26	65	
Nasal	0	0	0	0	0.046	1	4.3	0	0	0.222	1	2.5	0	0	0.698
Throaty	11	64.7	7	41.1		4	17.3	7	30.4		15	37.5	14	35	
Rate															
Adequate	16	94.1	13	76.4		21	91.3	13	56.5		37	92.5	26	65	
Fast	1	5.8	1	5.8	0.083	2	8.6	9	39.1	0.007	3	7.5	10	25	0.002
Slow	0	0	3	17.6		0	0	1	4.3		0	0	4	10	

decreased in samples of English counting. A moderate positive correlation was also found for the age female participants arrived in the USA and the rate in the Hebrew spontaneous speech samples (r=0.469, p=0.032). Once again, this corroborates a typical bilingual speaking pattern in which participants who arrived in the USA at a later age were associated with speaking Hebrew at an increased rate, most likely due to a first language dominance in Hebrew.

Acoustic analysis

Results of the Student's t-test for the acoustic analysis revealed some significant changes in acoustic voice parameters when comparing spontaneous speech samples of adult bilingual Hebrew/English speakers (Table 3). Pauses per minute were significantly higher when adult bilinguals spoke in English (mean=131.9) than in Hebrew (mean=118.9) for the total population (p=0.034).

When breaking down the total sample by gender, males demonstrated an increased mean F0 when speaking in English (mean=126.1) as compared to Hebrew (mean=122) (p<0.001), as well as an increased F0 variation when speaking in English (mean=282.5) (p=0.034). Females were shown to have statistically significant changes in their mean F0 when comparing Hebrew/English samples (means=197.7 and 188.6, respectively) (p<0.001). In contrast to findings from the male sample, females demonstrated a decreased mean F0 when speaking in English (mean=188.6) versus Hebrew (mean=197.7). No statistically significant changes were noted in words per minute when comparing Hebrew and English spontaneous speech samples in adult bilingual Hebrew/English speakers for the total population (means=107.1 and 147.8, respectively) (p=0.101), males (means=110.1 and 154.4, respectively) (p=0.25) and females (means=104.8 and 142.9, respectively) (p=0.315).

Correlation measures were analyzed to determine if the age the participants arrived in the USA were predictive of vocal parameter values studied in the research. For correlation analysis of acoustic vocal parameters, Pearson correlation for parametric variables was used to analyze the relationship between the age the participants arrived in the USA and duration, mean F0, F0 variation, pauses per minute and words per minute (WPM).

Table 2. Wilcoxon signed ranks test values for non-parametric perceptual variables (spontaneous speech task)

Spontaneous speech	Male					Female					Total				
Parameters	English		Hebrew		p-value	English		Hebrew		p-value	English		Hebrew		p-value
	n	%	n	%		n	%	n	%		n	%	n	%	
Vocal quality															
Roughness	10	58.7	6	35.2	0.273	13	56.4	14	60.8	0.829	23	57.5	20	50	0.596
Breathiness	4	23.5	4	23.5	>0.999	7	30.4	3	13	0.206	11	27.5	7	17.5	0.317
Strain	2	11.7	1	5.8	0.564	2	8.6	1	4.3	0.564	4	10	2	5	0.414
Extra characteristic															
Vocal fry	5	29.4	0	0	0.025	3	13	0	0	0.083	8	20	0	0	0.005
Glottal attack															
Adequate	2	11.7	6	35.2		5	21.7	8	34.7		7	17.5	14	35	
Soft	0	0	0	0	0.102	1	4.3	0	0	0.291	1	2.5	0	0	0.057
Hard	14	82.3	7	41.1		17	73.9	13	56.5		31	77.5	20	50	
No initial vowel	1	5.8	4	23.5		0	0	2	8.6		1	2.5	6	15	
Pitch															
Adequate	17	100	17	100		23	100	23	100		40	100	40	100	
Low	0	0	0	0	>0.999	0	0	0	0	>0.999	0	0	0	0	>0.999
High	0	0	0	0		0	0	0	0		0	0	0	0	
Resonance															
Adequate	5	29.4	2	11.7		11	47.8	2	8.6		16	40	4	10	
Nasal	0	0	0	0	0.180	0	0	0	0	0.013	0	0	0	0	0.005
Throaty	12	70.5	15	88.2		12	52.1	21	91.3		24	60	36	90	
Rate															
Adequate	15	88.2	14	82.3		22	95.6	21	91.3		37	92.5	35	87.5	
Fast	2	11.7	3	17.6	0.655	1	4.3	2	8.6	0.564	3	7.5	5	12.5	0.480
Slow	0	0	0	0		0	0	0	0		0	0	0	0	

Table 3. Paired samples Student's *t*-test for parametrical acoustic variables (spontaneous speech task)

Parameters	Male					Female					Total				
	English		Hebrew		p-value	English		Hebrew		p-value	English		Hebrew		p-value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Mean F0	126.1	21.7	122	19.4	<0.001	188.6	21.6	197.7	28.5	<0.001	–	–	–	–	–
F0 variation	282.5	138	187.1	136.8	0.034	263.8	112	226.3	91.1	0.239	–	–	–	–	–
Pauses/min	126.8	35.5	118.8	34.7	0.224	135.7	36.1	118.9	38.1	0.095	131.9	35.7	118.9	36.3	0.034
WPM	154.4	33.9	110.1	29.3	0.250	142.9	30.5	104.8	30.3	0.315	147.8	32.1	107.1	29.6	0.101

Caption: SD = standard deviation; F0 = fundamental frequency; WPM = words per minute

A moderate negative correlation between the age participants arrived in the USA and WPM in spontaneous speech English samples was found for the total population (r=-0.509, p=0.001) and for males (r=-0.637, p=0.006). This indicates that the participants who arrived in the USA at a later age were associated with a slower rate of speech in English which is reflective of a typical bilingual pattern when speaking in the second language.

DISCUSSION

The results of our study further contribute to research findings that language is a contributing factor to varying vocal characteristics. The study aimed to determine whether vocal parameters differ when bilingual Hebrew-English speakers spoke in Hebrew as compared to English. Following perceptual and acoustic analyses of speech samples, changes in perceptual vocal characteristics, such as resonance, the presence of vocal fry and glottal attack and acoustic measures of mean F0, F0 variation, pauses/minute were noted when comparing both languages during spontaneous speech.

Perceptual analysis of voice parameters among bilingual Hebrew/English speakers was significant for the increased presence of hard glottal attack and vocal fry in the total population and males when the subjects spoke in English versus Hebrew. Hard glottal attack refers to forceful collision of vocal folds upon initial production of a vowel. During perceptual analysis, the judge reported that there were fewer opportunities to assess glottal attack in Hebrew than in English due to a decreased production of vowels at initial position in words. While this may have potentially resulted in an increased incidence of hard glottal attack detected in the English samples, the significantly greater incidences of hard glottal attack exhibited by the bilingual sample when counting in English compared to in Hebrew serve to corroborate our findings in spontaneous speech. The counting samples were edited to include automatic counting from 1–8 in both languages. When comparing the frequency of initial vowels of both languages during this task, Hebrew presented with more initial vowels than English. This strengthens evidence that the higher incidence of hard glottal attack in spontaneously spoken English may be attributed to language-related cultural factors and not influenced by inherent phonological structures of the language that can decrease opportunity for perceptual observance of glottal attack.

A further finding that demonstrates changes in perceptual vocal quality was the increased perception of roughness among males while counting in English compared to in Hebrew. While this perceptual change was not noted in spontaneous speech, it is possible that, within automatic speaking tasks, such as counting, the presence of certain vocal quality characteristics is more easily perceived than in spontaneous speaking tasks in which the speaker may use compensatory vocal measures that can mask those characteristics. Previous research has found similar results in which different speaking tasks yielded different perceptual voice quality results[22,26,27]. While further studies in perceptual vocal quality differences between languages are needed to clarify the understanding of linguistic impact on vocal characteristics, it can be suggested that differing vocal mechanism behaviors that were found to be influenced by language in this study (e.g. increased hard glottal attack and vocal fry in English) may have impacted the likelihood of deviant vocal characteristics to be observed in English than in Hebrew. Findings related to changes in vocal quality features are supported in the literature in bilingual studies of English/Cantonese and Catalan/Spanish that indicated differences in vocal quality revealed through spectral analysis when comparing bilingual language samples[17,18].

The significant presence of vocal fry in the total population and males, as well as the tendency for women to produce vocal fry compared to the complete absence of vocal fry across the population when speaking Hebrew, may be attributed to cultural factors. Vocal fry, or "creaky voice", refers to a distinct low vibratory pattern produced at the vocal folds. Recent research has identified vocal fry as a current vocal trend in American English, particularly amongst female speakers, but also in males, that is not necessarily attributed as pathological voice behavior[28,29]. This may support a cultural-based explanation of an absence of vocal fry when the same subjects spoke in Hebrew compared to the appearance of vocal fry when speaking in English. The change in vocal parameters in this instance may signify a kind of vocal code switching when bilingual Hebrew/English speakers speak in English compared to Hebrew, given that recent studies have indicated vocal fry as a culturally-accepted vocal norm in Standard American English[28,29].

A final significant perceptual finding was an increase in the perceptual assessment of throaty resonance in Hebrew amongst the total population and in females when compared to a more adequate resonance in English during spontaneous speech. The change in resonance characteristics can be attributed to differences in the linguistic and phonological system of Hebrew. For instance, uvularized and pharyngealized phonemes (e.g. /χ/, /ʁ /, /ħ/ and / ʕ /) are characteristic of Hebrew which may relate to the difference in back resonance when compared to the more often nasalized or frontal resonance of English due to co-articulatory nasalization[30]. Future study can focus on corroborating perceptual findings on resonance with acoustic correlates by using spectral analysis to analyze formant changes amongst the Hebrew/English samples.

Changes in mean F0 were discovered in both the male and female groups. Acoustically, males were found to have a lower mean F0 when speaking in Hebrew than while speaking in English. Additionally, the male population was revealed to have a greater F0 variation in English than in Hebrew. F0 range findings indicate that, overall, when the male bilingual speakers spoke in English, they exhibited a wider range of intonation than when speaking in Hebrew. Since F0 is the acoustic parallel to psychological perceptions of pitch, these findings corroborate anecdotal evidence that male speakers can sound lower-pitched while speaking in Hebrew compared to in English, possibly due to a decreased mean F0 and F0 variation in Hebrew. These results are similar to cross-language and bilingual comparisons reported in the literature, where mean F0 and F0 variation were found to differ between languages such as Dutch and Japanese, bilingual English/Russian, bilingual English/Cantonese, English and Mandarin, English and

German and bilingual English/Catalan[8-18]. In contrast to mean F0 changes in males, females were found to have an increased mean F0 when speaking in Hebrew compared to English. This too supports the researchers' hypothesis based on anecdotal evidence that females may, at times, seem to exhibit a higher-pitched voice in Hebrew than when speaking in English.

From our findings, it is difficult to determine whether the change in acoustic vocal parameters is a result of code-switching to adjust to learned cultural norms of expected pitch or based on fundamental linguistic differences between Hebrew and English that influence physiological voice production. However, by focusing on a bilingual population in which the same speaker's voice was assessed in Hebrew and English spontaneous speaking tasks, changes in acoustic voice parameters were isolated to language impact, rather than to confounding variables such as age, personality or other personal factors which may explain such voice changes in a cross-language study. Although mean F0 changes were found to be statistically significant when comparing Hebrew/English speech samples of the same speaker, the perceptual correlate of pitch was not found to have significant changes when comparing both language samples using perceptual ratings.

In this study, the judge was asked to rate pitch using broad rating categories of low, adequate or high. This kind of rating may be appropriate to detect changes in deviant pitch characteristics between language samples. However, when comparing perceptual differences of pitch in the same speaker, perhaps a rating scale that is more sensitive to subtle changes that can be perceived in pitch, such as 1–10 rating scale or visual analog scale similar to that used by the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V), may be implemented to better corroborate acoustical findings. For the total group, it was shown that, when bilingual speakers spoke in Hebrew, they had greater pauses/minute than when they spoke in English. While this can be attributed to either the cultural/linguistic nature of the languages, it can also be explained by possibly stronger language dominance in English than in Hebrew in some of the participants.

A statistical comparison of speech sample durations in both languages was discounted from the study. Findings from paired samples Student's t-test revealed that English spontaneous speech samples were significant longer in duration than Hebrew spontaneous speech samples amongst the total population, males and females ($p<0.001$). In this case, the linguistic structure of both languages should be considered to account for these findings. The sample group was asked to speak about the weather in both Hebrew and English so that the content of the speech samples should be similarly matched.

Generally, Hebrew appeared to combine a greater amount of morphological units into one word, so that fewer words were produced to convey the same message when compared to English. Hebrew and English possess different morphological rule systems, such that a comparison of a sentence with identical content in both languages may not always yield a 1:1 word correlation. For instance, when the subjects were asked to produce a spontaneous speech sample related to the weather, in English the sentence "The weather today is very cold" is broken down into six words compared to the same content said in Hebrew — "Mezeg-avir hayom kar me'od", which would yield four words and a shorter sample duration. Therefore, while this study indicates an increased duration of speech in English than in Hebrew, it is questionable whether the calculation was influenced by the greater amount of words produced in English to convey a more concisely spoken message in Hebrew. Further, perceptual analysis findings in the automatic counting samples supported that Hebrew counting is perceived to be spoken at a faster rate than English counting. No statistical changes in rate were perceived in the spontaneous speech samples. While these results were consistent across the population, the results must be interpreted with caution. The judge's unfamiliarity with Hebrew may have influenced the perception of Hebrew as a faster language than English. Future studies may consider judges that are familiar with both or neither languages in order to more subjectively assess possible rate differences when comparing language samples.

By controlling for inter-individual differences with the use of bilingual participants, this study has isolated differences in the linguistic and phonological systems of the languages as a possible cause for variation in vocal characteristics, such as resonance and mean F0, as well as possible cultural influences that may relate to the presence of vocal fry in English in contrast to Hebrew. The differences in vocal parameters across languages indicated in this study corroborate results from previous research that reported acoustical differences in voice when comparing languages among bilinguals[9,14-18]. Our study expands these findings by revealing that perceptual analysis of cross-language samples in bilingual Hebrew/English speakers has also indicated vocal feature changes, specifically in resonance and in certain vocal quality characteristics. This verifies anecdotal evidence that people can perceive differences in voice characteristics when individuals switch between proficient languages.

Limitations of our study include the use of participants with varying levels of bilingualism. Many subjects appeared to have greater dominance in Hebrew than in English, or else more comfortable with English compared to Hebrew, as opposed to having equal levels of proficiency in both languages. The age the participant arrived in the USA was selected as a functional variable for correlation testing since it is likely to relate to the participants' age of second language acquisition and immersion in the cultural-linguistic environment of the second language, in this case, English, and may therefore be associated with certain vocal tendencies measured in the study. As noted in the correlations, the unbalanced language dominance may have influenced the increased rate in Hebrew compared to English associated with those participants who acquired English as a second language at a later age, rather than reflecting a vocal behavior isolated to linguistic impact which was the aim of the study. Subjects more dominant in one language may have been more likely to carry over vocal characteristics from their native language when speaking in their second language[15,18]. Therefore, it is possible that results would change depending on whether fluency was acquired at the critical age of language acquisition during which there is increased likelihood of attaining

a native-like fluency in both languages[30]. Additionally, an even larger sample of participants with more controlled levels of bilingualism may yield more refined results as to the differing vocal characteristics in Hebrew versus English.

Future studies may want to extend research to other languages and control for differences that may result from varying levels of bilingualism in their sample population. This can be achieved by surveying balanced bilingual' populations, who possess equal dominance in both languages. Additionally, while this study analyzed differences in vocal parameters in bilingual Hebrew/American English speakers, the population was specifically fluent in Standard American English, which is likely to possess varying vocal characteristics to other dialectal forms of English found across the USA[30]. A cross-comparison of bilingual speakers with second language proficiency amongst varying English dialects would be interesting to study in order to better note vocal differences in bilinguals related to linguistic structures of Standard American English versus cultural dialectal factors.

As mentioned earlier, future studies may want to look at perceptual voice differences in bilinguals using judges who are either familiar or unfamiliar with both languages to increase subjectivity of analysis of vocal parameters, such as rate of speech, resonance, pitch and vocal quality. Additionally, since many bilingual studies have revealed statistical changes in mean F0 and F0 variation between languages, it would be interesting to corroborate results perceptually with a rating scale that may be sensitive to changes in pitch within the same speaker when switching languages.

In conclusion, examination of differences in vocal parameters when adult bilingual speakers talk in Hebrew as compared to English reveals differences in both perceptual and acoustical measures of voice. These results contribute to the accumulating research on the influence of language on vocal characteristics. Evidence from these studies will have important implications for clinicians to be aware of cultural-linguistic impact on voice production when assessing voice and to be sensitive to the existence of varying vocal norms across languages. Specifically, when describing characteristics of an individual's voice that may appear pathological, clinicians should consider in their differential diagnosis whether the feature may be related to the linguistic or cultural properties of that individual's language[12,28,29].

Voice differences attributed to a cultural/linguistic element carry practical implications for the administration of accent modification therapy and professional accent training in which professionals may better assist clients in matching the voice characteristics of the target language, such as a possible increase in intonation and pitch for male speakers when speaking in English as compared to Hebrew or alterations in resonance as indicated in the present study.

**All authors contributed to the study and/or manuscript. All are responsible for the contents and warrant that he or she had a significant participation in the work and has reviewed the updated manuscript submitted for consideration. CN and LN were in charge of the project and were responsible for data collection; GO responded for the study design and for general guidance and correction of the final manuscript; all authors contributed to the elaboration of the manuscript.*

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