The Effect of Smoking on the Fundamental Frequency of the Speaking Voice

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Summary: Objective. Little is known about the impact of smoking on voice acoustics. Some studies have found that tobacco affects the fundamental frequency of the voice, whereas others have not. This study aimed to overcome the major methodological limitations observed in previous studies by strictly controlling several variables that could clarify the effect of smoking on the speaking voice.

Methods. Lebanese men were chosen for this study. Thirty nonsmokers, 30 cigarette smokers, and 30 water-pipe smokers were matched on the basis of age, height, and weight. The 90 participants were asked to complete the Voice Handicap Index, sustain the vowel /a/, read 10 sentences in French and Arabic, and speak spontaneously in both languages. The mean fundamental frequency (F0), speaking fundamental frequency (SFF), jitter, and standard deviation of F0 were measured using *Praat* and *Vocalab4* and were compared between the groups.

Results. The Voice Handicap Index scores differed significantly between nonsmokers and cigarette smokers and between nonsmokers and water-pipe smokers. Results also show that cigarette smokers' F0 and SFF were significantly lower than nonsmokers' results. No significant differences were found between water-pipe smokers and nonsmokers. The jitter and the standard deviation of F0 did not differ significantly between the two groups.

Conclusions. Our findings clearly demonstrate the effect of smoking on the voice: smokers reported more voice complaints, and cigarette smokers presented lower F0 and SFF in French and in Arabic when age, height, and weight were controlled. Further investigations using similar strict controls over individual variables and additional measures are encouraged to better understand the effect of water-pipe smoking on the voice.

Key Words: Voice−Fundamental frequency−Smoking−Cigarette−Water pipe.

INTRODUCTION

Smoking is undeniably harmful to one's health and particularly affects the vocal apparatus. For instance, Levendoski et al[1] showed that exposure of animals to cigarette smoke caused laryngeal damage. More specifically, Levendoski et al observed damage to the epithelial barrier, such as disturbed epithelial stratification, hyperplasia, desquamation, and reduced number of desmosomes, as well as damage to the mucus barrier of the larynx, with thicker, more adhesive mucus after exposure to cigarette smoke. Kelleher et al[2] showed that the microstructure of the vocal ligament itself is also affected. Comparing smokers and nonsmokers, Kelleher et al observed less collagen fiber alignment in the midmembranous region and a higher collagen fiber dispersion coefficient in the smokers group. The harmful effects of smoking are not limited to cigarette consumption. Recent studies have investigated the consequences of water-pipe smoking for health and proved that it was related not only to a higher risk of infection (eg, hepatitis, herpes, and tuberculosis) and respiratory and cardiovascular diseases[3] but also to cancer, especially of the head and neck, esophagus, and lungs.[4]

Tobacco consumption with a water pipe has gained popularity worldwide in the past decade, especially among youths.[5] The fruity flavor of water-pipe tobacco, the social nature of water-pipe smoking, and misperceptions concerning the effect of this smoking method (eg, belief that toxic elements are filtered out by the water bowl) seem to be the main reasons for this increase.[6]

Although the consequences of smoking (cigarettes or water pipes) for health are well documented, little is known about the impact of smoking on voice acoustics. Kelleher et al[2] noted that smoking is responsible for chronic irritation, an increase in vocal fold mass, and cellular aberrations. Gonzalez and Carpi also showed that smoking has acoustic consequences (increase in jitter and lower fundamental frequency [F0]).[7]

Several authors have examined the effect of smoking on the voice, but the results are not consistent across studies. For instance, one study showed that the F0 in a 30-minute session of water-pipe smoking decreased in women but increased in men.[8] Another study, which compared nonsmokers with cigarette smokers and water-pipe smokers, found no acoustic differences between water-pipe smokers and nonsmokers, despite the histologic changes observed (ie, edema, hyperplasia, and thick mucus).[9] When cigarette smokers are examined, the same findings are reported: anatomic changes in the vocal folds, differences in the perturbation parameters of F0, but no decrease in the mean F0. Also, smokers reported higher Voice Handicap Index (VHI) scores than nonsmokers[10] (high scores are correlated with a vocal complaint in everyday life[11]). Only one study reported a decrease in the mean F0 for cigarette smokers when age and gender were controlled.[12]

The inconsistent findings could be attributed to the small sample sizes of some studies, but also to insufficient control

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over variables such as gender, age, height, and weight. These variables (ie, gender, age, and height) have an influence on the pitch of speech (ie, mean F0).[13−15] For example, the length of the vocal folds is correlated with the subject's height.[13] Moreover, the mean F0 is lower for men than for women.[14] Controlling these variables is therefore crucial to investigate the effect of smoking on the F0 of the voice.

The present study was designed to overcome these limits by strictly controlling age, gender, height, and weight, to clarify the effect of smoking (both cigarettes and water pipes) on acoustic parameters of the speaking voice. The parameters investigated were the mean F0 of sustained vowels, jitter (ie, the average absolute difference between consecutive periods divided by the average period), the standard deviation of F0 (SDF0) (ie, SDF0 in the analyzed sample), and the speaking fundamental frequency (SFF). To do so, we focused on the Lebanese population. The choice of Lebanese participants is grounded on the fact that the prevalence of smokers is particularly high (about 36% of the population) and problematic (each year, 6470 people die in Lebanon because of smoking, according to the Ministry of Public Health in 2015[16]).

By comparing vocal productions by water-pipe smokers, cigarette smokers, and nonsmokers, we expected to observe the main effect of smoking on both VHI scores and acoustic parameters relative to vocal fold mechanisms. Indeed, because smoking leads to anatomic and histologic changes in the larynx and the vocal folds,[1,2] the vibration (frequency and regularity) of the vocal folds might be affected. By carefully controlling age, gender, height, and weight, we expected to observe that nonsmokers spoke with a higher mean F0 and less perturbation (ie, low jitter and SDF0) than smokers. If the consequences of smoking are specific to changes in the vibratory mechanisms of the vocal folds, this effect should appear regardless of language (ie, Arabic or French) and task (ie, sustained vowel, spontaneous speech, and reading). In addition to clarifying the effect of smoking on the voice, the present study investigated potential differences based on the consumption mode (ie, cigarette vs. water pipe). The chemical composition of cigarette smoke and water-pipe smoke is different (ie, more phenol and benzene in water-pipe smoke[17]). Finding changes in the acoustic of the voice could possibly help in fighting against wrong beliefs and against the underestimation of the consequences of smoking.

METHODS

Participants

Ninety Lebanese men aged 25−55 years old ($M = 33.35$, standard deviation [SD] = 8.59) were assigned to one of three groups depending on their smoking habits: the control group or the nonsmokers group (NSG), namely, men who had never smoked; the cigarette smokers group (CG); and the water-pipe smokers group (WG). All smokers had a history of smoking that lasted for more than 10 years. The participants were matched based on their age, height, and weight, according to an anamnestic questionnaire. As shown in Table 1 and confirmed with one-way analysis of variance (ANOVA), the three groups did not differ significantly with regard to age, height, and weight. Also, the Mann-Whitney test showed that the number of years of smoking did not differ significantly between the cigarette and water-pipe smokers. In other words, the selection of the participants ensured homogeneity between the groups with regard to gender, age, and physical characteristics, which allowed for a focus on the effects of smoking (and of mode of smoking) by limiting the interindividual differences between groups. Matching cigarette and water-pipe smokers was challenging. The frequency of cigarette smoking was higher than the frequency of water-pipe consumption, but the amount of tobacco in cigarettes was much lower (1 g of tobacco per cigarette) than the amount of tobacco in water pipes (one water pipe is filled with 10−20 g).[18] Therefore, our criterion required a minimum of 10 cigarettes or 1 water pipe per day. We did not set a precise number of maximum of cigarettes or water pipes per day but made sure to keep a similar variability in smoking habits between groups. In the present study, seven participants smoked more than 30 cigarettes per day (or three water pipes per day), whereas all the others smoked between 10 and 20 cigarettes per day (or one or two water pipes per day).

Voice professionals (eg, teachers, priests, and singers), people who suffered from acid reflux, asthma, allergies, or ear, nose, and throat infections, and people who had had a thyroidectomy or any other laryngeal surgery were excluded from the study.

Material

Vocal productions were recorded using a Sennheiser HS 2−5 Microphone 106098 Sennheiser (Wedemark, Germany) and a Marantz Professional Solid State Recorder PMD67

TABLE 1.
Mean (Standard Deviation) Age, Height, Weight, and Number of Years as Smokers of the Participants in the Three Groups (NSG, CG, and WG)

	NSG	CG	WG	Comparison
Age (y)	33.3 (8.75)	33.5 (8.71)	33.3 (8.62)	$F = 0.00$, $P = 0.99$
Height (m)	1.78 (0.06)	1.77 (0.05)	1.78 (0.06)	$F = 0.04$, $P = 0.96$
Weight (kg)	82.65 (13.66)	81.27 (13.89)	89.7 (14.84)	$F = 3.06$, $P = 0.051$
Years of smoking	—	15.7 (7.73)	12.8 (3.63)	$U = 356$, $P = 0.17$

Notes: The last column contains the results of the one-way ANOVA (and P values) and the Mann-Whitney test performed to compare the groups for each variable.

20090836003470 (Eindhoven, The Netherlands). Room temperature ($M = 26.6$, SD = 1.34°C), humidity level ($M = 53.6$, SD = 11.01% relative humidity), and sound pressure level ($M = 32.08$, SD = 3.12 dB) were measured before each recording session using the PCE-353 sonometer, Version 1.0 (Strasbourg, France), and the Hygromaster Protimeter Thermo-Hygrometer (GE Sensing, Melrose, MA).

Procedure

After signing the consent form approved by the ethics committee of the Faculty of Psychology, Speech and Language Therapy, and Education Sciences of the University of Liège, the participants were asked to complete an anamnestic questionnaire and the VHI. Several vocal productions were then recorded. Participants were asked to produce three /a/ vowels that lasted between 3 and 5 seconds and to read a list of sentences in French and in Arabic. The French material consisted of 10 phonetically balanced sentences from list number 9 of *Listes des phrases de Combescure*.[19] The Arabic material consisted of list number 1 of the *20 Lists of Ten Arabic Sentences*,[20] which is the Arabic version of the Combescure list. An additional sentence (from another list) was added to the 10 sentences in the original list to avoid a potential descending intonation on the last sentence. Finally, the participants were asked to introduce themselves in French and in Arabic (name, home town, and profession). Languages and tasks were counterbalanced across participants.

Acoustic analyses

The recordings of the sustained vowel were analyzed with *Praat*[21] using the autocorrelation method, a pitch range of 10−500 Hz, and a sampling rate of 44,100 Hz. The mean F0, jitter, and SDF0 were extracted for each vowel and then averaged for each participant.

The reading and spontaneous language tasks were analyzed with *Vocalab4*[22] using harmonic coherence analysis and detection of the pitch peak, a pitch range of 85−1000 Hz, and a sampling rate of 22,000 Hz.

For the reading task, we used *Audacity 2.1.1* (Computer program, Version 2.1.1., retrieved from http://audacity.sourceforge.net/) to discard the last sentence (ie, the additional material) and then analyzed the SFF of the list of sentences using *Vocalab4* for each participant and each language. For the spontaneous language task, *Vocalab4* was used to extract the SFF of the sample produced by each participant in each language separately.

RESULTS

Participants' vocal complaints

As Figure 1 shows, and as confirmed with the Kruskal-Wallis test, the scores on the VHI questionnaire differed between groups ($K = 9.83$, $P = 0.007$).

The linear contrasts, with a Bonferroni correction, highlighted the significant differences between nonsmokers and cigarette smokers, as well as between nonsmokers and water-pipe smokers (Table 2). The scores were lower than 20 and thus cannot be considered as pathologic.[11] No significant difference was found between the two groups of smokers.

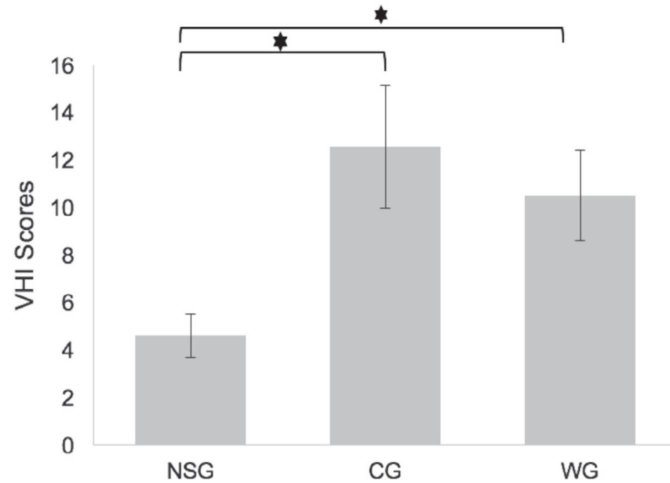

FIGURE 1. Mean values of the VHI scores for the three groups: NSG, CG, and WG. Error bars represent a confidence interval of 95%. Asterisks represent significant differences ($P < 0.05$), as revealed by the linear contrast test.

TABLE 2.
Linear Contrast Z and P Values for the VHI Scores for the Three Groups (NSG, CG, and WG)

	CG	WG
NSG	$Z = 2.88$, $P = 0.004$*	$Z = 2.55$, $P = 0.011$*
CG	—	$Z = 0.19$, $P = 0.850$

Notes: The asterisks represent significant contrasts according to the adjusted significance level ($\alpha = 0.016$).

Effect of smoking on F0

As noted previously, the participants were matched based on their age, height, and weight. For each task and each acoustic parameter examined (ie, mean F0, jitter, and SDF0 for sustained vowels; SFF for speech), repeated measures ANOVAs and the Tukey honestly significant difference (HSD) were applied to compare the three groups (ie, NSG, CG, and WG). In other words, we examined the effect of smoking and the type of smoking on each measure.[a] The choice of the analytical procedure (ie, repeated measures ANOVAs) was possible, thanks to the strict control of age, weight, and height (matched between groups), which minimized the interindividual differences between groups (other than the smoking activity and the type of smoking). For the reading and spontaneous speech tasks, the language (ie, French or Arabic) was also examined as a within-subject variable.

[a]Note that correlational analyses were also carried out within the smokers group to examine the relation between the amount of smoking and the acoustic features. None of the correlation coefficients reached the significance level of 0.05. Detailed results are not reported here in order not to lose the main focus of the study, which is the effect of smoking and the type of smoking on the F0 of the speaking voice.

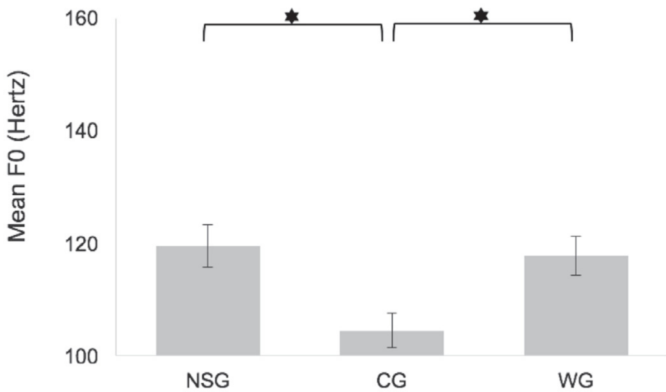

FIGURE 2. Mean F0 for the sustained vowel task for the three groups: NSG, CG, and WG. Error bars represent a confidence interval of 95%. Asterisks represent significant differences ($P < 0.05$), as revealed by the Tukey HSD.

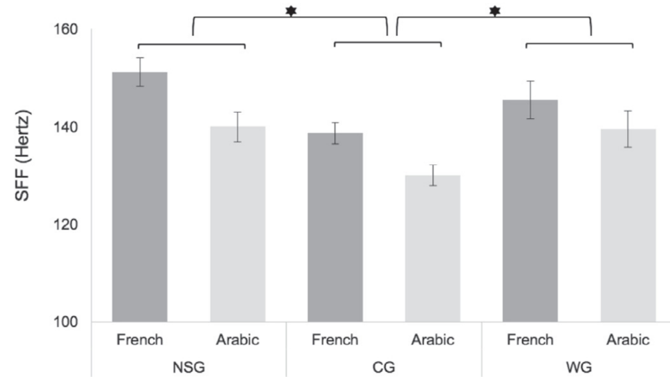

FIGURE 3. Mean SFF for the reading task for the three groups: NSG, CG, and WG, in the two language conditions (French and Arabic). Error bars represent a confidence interval of 95%. Asterisks represent significant differences ($P < 0.05$), as revealed by the Tukey HSD.

Sustained vowel task

The repeated measures ANOVA revealed an effect of smoking on the mean F0 ($F(2, 28) = 10.52$, $P < 0.001$, $\eta_p^2 = 0.27$). As illustrated in Figure 2 and confirmed with the Tukey HSD, the cigarette smokers ($M = 104.47$, SD = 14.03) had a lower mean F0 than the nonsmokers ($M = 119.43$, SD = 17.19) (HSD: $P < 0.001$). Interestingly, the mean F0 of the water-pipe smokers ($M = 117.82$, SD = 15.99) was significantly higher than the mean F0 of the cigarette smokers (HSD: $P = 0.002$) and was comparable with the mean F0 of the nonsmokers (HSD: $P = 0.846$).

As reported in Table 3, the perturbation measures (ie, jitter and SDF0) did not significantly differ between the two groups.

Reading task

The repeated measures ANOVA revealed a main effect of smoking on the mean SFF ($F(2, 58) = 6.53$, $P = 0.003$, $\eta_p^2 = 0.18$). As shown in Figure 3 and confirmed with the Tukey HSD, a difference was found between the nonsmokers and the cigarette smokers, with a lower mean SFF for the cigarette smokers speaking both French and Arabic ($M = 134.33$, SD = 10.77) than for the nonsmokers ($M = 145.52$, SD = 14.67) (HSD: $P = 0.003$). The SFF of the water-pipe smokers did not differ significantly from the SFF of the nonsmokers (HSD: $P = 0.599$) but was significantly higher than the SFF of the cigarette smokers ($M = 134.33$, SD = 10.77) (HSD: $P = 0.037$).

The same analysis revealed a main effect of language ($F(1, 29) = 78.84$, $P < 0.01$, $\eta_p^2 = 0.73$): SFF was higher in French ($M = 145.09$, SD = 14.8) than in Arabic ($M = 136.61$, SD = 14.54). This finding can be seen in Figure 3 and was confirmed with the ANOVA. However, there was no interaction between the group (ie, NSG, CG, or WG) and language (ie, French or Arabic) variables ($F(2, 58) = 2.81$, $P = 0.068$, $\eta_p^2 = 0.08$). In other words, the effect of smoking on SFF occurred whatever the language.

Spontaneous speech task

The results for the spontaneous speech task were similar to those for the reading task. Indeed, the repeated measures ANOVA revealed a main effect of smoking on the mean SFF ($F(2, 58) = 5.49$, $P = 0.007$, $\eta_p^2 = 0.16$); a main effect of language ($F(1, 29) = 11.36$, $P = 0.002$, $\eta_p^2 = 0.28$); but no interaction between the two variables ($F(2, 58) = 0.89$, $P = 0.417$, $\eta_p^2 = 0.03$). As illustrated in Figure 4 and confirmed with the Tukey HSD, there was a difference between the nonsmokers and the cigarette smokers, with a lower mean SFF for the cigarette smokers ($M = 126.48$, SD = 13.03) than for the nonsmokers ($M = 134.98$, SD = 13.46) (HSD: $P = 0.017$). The SFF of the water-pipe smokers did not differ significantly from that of the nonsmokers (HSD: $P = 0.998$) but was significantly higher than the SFF of the cigarette smokers ($M = 135.15$, SD = 15.09) (HSD: $P = 0.015$). The main effect of language confirmed the higher SFF in French ($M = 133.73$, SD = 15.10) than in Arabic ($M = 130.68$, SD = 13.61). However, as with the reading task, the effect of smoking on the participants' SFF was not affected by the spoken language (ie, no interaction between the group and language variables).

TABLE 3.
Mean (Standard Deviation) Values for Jitter and SDF0 for the Three Groups (NSG, CG, and WG)

	NSG	CG	WP	Repeated Measures ANOVA
Jitter (%)	0.47 (0.17)	0.48 (0.17)	0.76 (1.37)	$F = 1.21$, $P = 0.306$
SDF0 (Hz)	2.73 (1.44)	2.95 (4.00)	3.08 (2.07)	$F = 0.12$, $P = 0.891$

Notes: The last column contains the results of the repeated measures ANOVA.

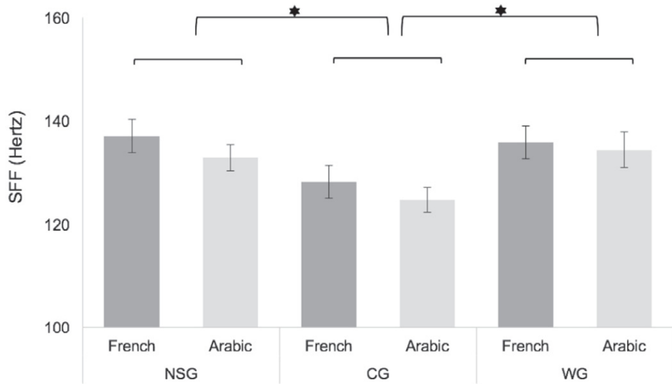

FIGURE 4. Mean SFF for the spontaneous speech task for the three groups: NSG, CG, and WG, in the two language conditions (French and Arabic). Error bars represent a confidence interval of 95%. Asterisks represent significant differences ($P < 0.05$), as revealed by the Tukey HSD.

DISCUSSION

The purpose of the present study was to investigate the effect of smoking (cigarette and water pipe) on the acoustics of the speaking voice, with strict control over age, gender, height, and weight. As expected, we observed an effect of smoking on the F0 of the voice. However, our hypothesis was only partially verified because differences were found only between nonsmokers and cigarette smokers.

Like the cigarette smokers, water-pipe smokers had a higher level of vocal complaints than nonsmokers (the scores were not pathologic in either case), but their complaints were not reflected acoustically. We tried to explain this result, but our explanation remains hypothetical because of the lack of scientific evidence. It is possible that tobacco particles in a water pipe might stick to the sides of the pipe's hose while traveling to the mouth, thus reducing the number of particles that arrives to the laryngeal mucosa. Consequently, the damage to the voice parameters could be reduced. This explanation should be interpreted with great caution because it is hypothetical. The difference observed between cigarette and water-pipe smokers with regard to mean F0 and SFF might also be attributed to the frequency of smoking. Indeed, water-pipe users may go up to 24 hours without smoking, whereas some cigarette users consume a cigarette every 30 minutes. Moreover, some of the cigarette smokers reported having smoked a cigarette immediately before coming to the session. We cannot rule out the possibility that the frequency of smoking and the time between the most recent tobacco consumption and the test session may have influenced the results. Further studies controlling specifically for these variables are therefore encouraged.

However, the fact that we found negative results (ie, no significant difference between nonsmokers and water-pipe smokers) does not exclude a possible effect of water-pipe smoking on the speaking voice. Potential differences might be captured by acoustic and aerodynamic parameters that were not tested in the present study, such as the harmonics-to-noise ratio, the voice onset time, and the phonation quotient. Also, we believe that a perceptual analysis of the material could be beneficial and encourages such approach in future studies. This type of analysis could not only highlight changes at a perceptual level but also would certainly help in identifying the acoustic parameters to quantify.

Although the effect of water-pipe smoking needs to be further investigated, our study clearly shows the effect of cigarette smoking on the speaking voice, and specifically on the mean F0 in the sustained vowel task and SFF in the reading and spontaneous language tasks. Interestingly, Lebanese men had a lower SFF in Arabic than in French for both reading and spontaneous language, but the effect of smoking was consistent across languages (ie, lower SFF in cigarette smokers). The effect of language might be attributable to the linguistic content of the material (more back phonemes in Arabic). The effect could also be attributed to greater stress[23] when speaking in a foreign language (Arabic was the participants' mother tongue) and thus higher SFF in French. In any case, the main effect of smoking on the SFF supports the observation that smoking has an effect on the larynx and the vibration of the vocal folds, independent of the language spoken or the nature of the vocal production. We believe that reporting this kind of scientific evidence could be used in prevention programs.

Finally, we did not observe any difference between groups with regard to the perturbation parameters, namely, jitter and SDF0. This surprising finding, when examined individually, could suggest that the vocal folds are not affected. However, as reported earlier, the F0 measurements confirmed that cigarette smoking affects the larynx and the vibration of the vocal folds. Perturbation parameters such as jitter and SDF0 get higher when the vibration of the vocal folds is asymmetric. In the present case, this discrepancy between measurements (ie, no difference for perturbation parameters but group differences for F0 measurements) suggests that smoking damages vocal folds in their entirety. The tissue might develop an edema covering the whole cord, as a consequence of which the vocal cords' mass will increase. Therefore, F0 decreases but is not necessarily associated with asymmetric vibrations. The nature of the task could also be a reason for these findings. We might hear hoarseness in a smoker's voice when he speaks (connected speech), but in the present study, we investigated this feature with a sustained vowel. The differences between the two tasks might therefore explain the absence of results.

To sum up, some of the acoustic measures analyzed proved that smoking affects the voice (F0 and SFF), whereas the other parameters did not differ between smokers and nonsmokers (jitter and SDF0). Acoustic measures cannot replace a visual examination of the laryngeal structure, but these results definitely provide information to guide future research designed to fully understand the anatomic and histologic changes associated with smoking.

CONCLUSIONS

The present study clearly demonstrates the effect of cigarette smoking on the speaking voice when gender, age, height, and weight are controlled. In addition to providing concrete information about the consequences of smoking for a daily life activity (ie, speaking), which could be applied in prevention programs, the present study paves the way for further research focusing on water-pipe smoking and, more generally, on the specific anatomic or histologic changes due to smoking.

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