The Moderating Effect of Frequent Singing on Voice Aging

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Summary: The effects of aging on voice production are well documented, including changes in loudness, pitch, and voice quality. However, one important and clinically relevant question that remains concerns the possibility that the aging of voice can be prevented or at least delayed through noninvasive methods. Indeed, discovering natural means to preserve the integrity of the human voice throughout aging could have a major impact on the quality of life of elderly adults. The objective of this study was therefore to examine the potentially positive effect of singing on voice production. To this aim, a group of 72 healthy nonsmoking adults (20–93 years old) was recruited and separated into three groups based on their singing habits. Several voice parameters were assessed (fundamental frequency [f0] mean, f0 standard deviation [SD], f0 minimum and f0 maximum, mean amplitude and amplitude SD, jitter, shimmer, and harmonic-to-noise ratio) during the sustained production of vowel /a/. Other parameters were assessed during standardized reading passage (speaking f0, speaking f0 SD). As was expected, age effects were found on most acoustic parameters with significant sex differences. Importantly, moderation analyses revealed that frequent singing moderates the effect of aging on most acoustic parameters. Specifically, in frequent singers, there was no decrease in the stability of pitch and amplitude with age, suggesting that the voice of frequent singers remains more stable in aging than the voice of non-singers, and more generally, providing empirical evidence for a positive effect of singing on voice in aging.

Key Words: voice–aging–singers–perturbation measures–fundamental frequency.

INTRODUCTION

The human voice is an important carrier of human emotions, and it is also the foundation of human verbal communication throughout the entire life span. Unfortunately, the human voice undergoes several important acoustical changes throughout aging.[1–5] For many individuals, age-related voice changes have a negative impact on communication and social participation,[6–9] and therefore on the quality of life. Age-related changes in voice production are widespread and appear to have a complex and multifactorial etiology. Indeed, multiple anatomical and physiological age-related changes affecting the vocal tract, the larynx, and the respiratory system have been documented.[2,10–19] These include the ossification of the laryngeal cartilages; atrophy of the laryngeal muscles, lamina propria, glands, and connective tissues; a loss of ligament elasticity; bowing of the vocal folds; changes in the innervation of the larynx; and neuromuscular degeneration. Changes in the amount and quality of secretions and changes in each layer of the mucosa also appear with aging.[11,20] These anatomical and physiological changes can lead to a reduction of the vibration of the vocal folds, a reduction of adduction of the vocal folds (ie, bowing in presbyphonia), and an increased laryngeal muscle tension (especially for men).[1,2,10,13,21] Hormonal changes in menopause can also contribute to increased vocal fold swelling and edema, which in turn can lower the fundamental frequency (f0).[22,23] Acoustically, the voice undergoes several important changes in aging affecting the pitch, amplitude, and quality of the voice. Changes in f0 have been most thoroughly investigated. In men, f0 declines until the fifth decade and rises gradually after.[2,21,24,25] In women, there appears to be a steady decline of f0 with age.[4,21,24–27] For both men and women, control over vocal pitch tends to decline with age as shown by an increase in the variability of f0 (measured in standard deviations [SDs]), meaning that f0 becomes less stable with age.[27–30] In contrast to the well-documented effects of age on f0, the relation between age and measures of voice perturbation is less clear. Yet perturbation measures are important because they can reveal instability of the vocal fold vibration (jitter), irregularity of glottic closure (shimmer), and loss of vocal fold adduction (harmonic-to-noise ratio [HNR]). Moreover, these measures are widely used in clinical settings. For jitter, the literature is not entirely consistent. Indeed, whereas some studies have shown an increase in jitter with age,[24,29,31,32] other studies report no effect of age.[4,30,33] It has been suggested that changes in jitter are related to physiological changes rather than to chronological age.[33] In sum, the effect of aging on jitter remains uncertain. For shimmer (ie, regularity of glottal opening, and particularly closure), there are also some inconsistencies. For example, although some studies have shown age effects on shimmer in both men and women,[1,24,34] others have found changes in men but not in women.[4] One factor that may account for some of the differences across studies in terms of measures of perturbation is the recording process. Control of recording amplitude and mean f0 have been reported to influence shimmer and jitter significantly.[35–37] Presbylaryngitis (vocal cord atrophy) is also frequent but not universal in aging, and can be confounded with certain characteristics of the normally aging voice.[38] Finally, because the gap between the vocal folds tends to increase with age, middle-aged and older adults tend to have lower HNR (ie, noise level in the voice) values compared with young adults.[24,34] However, others have found changes in women but not in men,[6] or did not observe age differences in HNR.[4] In

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sum, although some inconsistencies remain concerning measures of voice perturbation, it is clear from the literature that aging affects the production of voice at multiple levels.

Early reports have observed that the acoustics of singers' voices differ from that of non-singers, including greater amplitude achieved at various frequencies.[39,40] Singing is also known to be associated with increased voice stability,[41] wider phonation range,[40–43] and increased maximal phonation time.[43,44] Moreover, it has been shown that singing training has a positive and quantifiable effect on voice control in children and teenagers with normal voices.[45,46] Consistent with this idea, a few studies have examined the effect of aging on singers' voices, and observed that the voice of middle-aged and older singers is more stable and has greater amplitude compared with the voice of non-singers.[47,48] Older singers also showed significantly higher speaking fundamental frequency (SFF) than older non-singers during a standardized reading task.[48–50] Understanding the nature and extent of age-related voice decline, as well as vocal habits that may provide protection against negative age effects, is key to developing new interventions to delay the onset of—and potentially prevent—these difficulties, which could have a major impact on the quality of life of elderly adults.

The goal of the present study was to characterize the effect of aging on a large number of acoustical voice parameters in two different contexts (production of a sustained vowel, and overt reading of a standardized passage) in a group of healthy singers and non-singers. Although many studies have examined voice aging, as discussed in the previous paragraphs, the present study is unique in that we examined voice in both a standard (sustained vowel production with controlled amplitude) and a more ecological context (passage reading), and that we analyzed a large number of voice quality and stability measures (12 acoustical parameters were studied). Most importantly, we examined the potentially positive effect of singing on 12 acoustical parameters using a powerful moderation analysis. In line with the literature, we hypothesized that aging would affect most voice parameters but that singing would moderate this effect. Finding a positive effect of singing on voice production in aging could have immediate and broad practical applications for the growing population of senior citizens.

METHODS

Participants

The study comprised a total of 74 healthy nonsmoking participants recruited through email, as well as through posters and flyers distributed in the community. Of the original sample, two participants were excluded because of technical issues that rendered unusable their audio samples. The remaining 72 participants (28 men, 44 women; total mean age ± SD: 51.15 ± 20.05; range: 20–93 years) were included in the analysis. The sample was divided into three groups based on their age (young: 20–39; middle-aged: 40–65; and old: 66–93 years old; Table 1). All participants were native speakers of Canadian French; had normal or corrected-to-normal vision; no self-reported history of speech, voice, language, swallowing, psychological, neurological, or neurodegenerative disorders; and no self-reported history of drug or alcohol abuse. Participants were screened for depression using

TABLE 1.
Participants' Characteristics

	Men			Women			All					
		Age			Age		Education (in years)		GDS		MoCA	
Group	N	Mean ± SD	Range	N	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Young	12	29.08 ± 6.04	20–38	14	27.64 ± 4.25	23–37	17.9 ± 3.01	11–24	3 ± 2.43	0–8	28.73 ± 1.34	25–30
Middle-aged	9	56.78 ± 7.97	44–65	17	55.12 ± 7.98	40–65	16.98 ± 3.38	12–24	1.81 ± 2.67	0–10	28.04 ± 1.78	25–30
Older	7	72.71 ± 3.9	68–78	13	76.15 ± 8	67–93	15.8 ± 4.1	7–24	2.25 ± 2.77	0–9	27.3 ± 1.53	25–30
Total	28	48.89 ± 19.48	20–78	44	52.59 ± 20.05	20–93	16.99 ± 3.52	7–24	2.36 ± 2.63	0–10	28.08 ± 1.64	25–30

Abbreviations: GDS, Geriatric Depression Scale; MoCA, Montreal Cognitive Assessment.

the Geriatric Depression Scale,[51] and their cognitive functioning was evaluated using the Montreal Cognitive Assessment scale (mean score: 28.08 ± 1.64 SD; range: 25–30).[52] Participants were also screened for hearing deficits using audiological assessments (pure tone average), which confirmed that their hearing capacities were within normal limits according to age. All participants were screened for their singing habits using a questionnaire that was developed in the laboratory (Singing assessment section). The study was approved by the Research Ethics Committee of the Institut Universitaire en Santé Mentale de Québec (project #294–2011). Informed written consent was obtained from all participants, and they were compensated for their participation (10$ CAN).

Singing assessment

Participants answered a questionnaire on singing habits. This included questions about singing context (eg, lessons, everyday casual singing, singing in a band), singing amplitude (low, normal, high), singing frequency (every day, at least once a week, etc), and singing training. We then classified participants into three groups based on the self-reported frequency of their singing activity (Table 2). We could not categorize them based on other factors because of our small sample and heterogeneous singing habits. This grouping was used in the moderation analyses.

Procedures

Voice recording

All recordings were performed under identical conditions. Each participant was seated comfortably either in a quiet room or in a sound-attenuated room and completed two tasks: (1) sustained phonation of the vowel /a/, and (2) propositional speech. Participants generally completed the tasks within 30 minutes. Shorts breaks were given as needed. For all tasks, participants' responses were recorded using a high-quality multidirectional head-worn microphone (Beta 53, Shure, Illinois, United States) connected to a sound card (Fast Track C400, M-Audio, Rhode Island, United States), which was connected to a laptop computer. All responses were recorded with *Audacity* software (version 2.0.3; Free Software Foundation, Maine, United States) at a sampling rate of 44.1 kHz and 32 bits of quantization. Samples were saved in .wav format on our local server at Institut Universitaire en Santé Mentale de Québec.

(1) Vowel /a/. For this task, participants produced the vowel /a/ for as long as possible, five times, with a short pause between each production. The participants produced the vowel at a "comfortable everyday pitch," that is, a pitch level not associated with subjective muscular tension or discomfort during phonation. Although comfortable pitch can be seen as subjective, it is a commonly used metric for the study of voice.[4,6,27,34] To control for amplitude, a digital sound meter was placed 65 cm away from the mouth of the participant. The target amplitude was set at 80 dB SPL (sound pressure level) to prevent biases in acoustical measurements of jitter, shimmer, and HNR.[35,36]

(2) Propositional speech. For this task, participants read a 2-minute standardized passage called « La bise et le soleil » (*the wind and the sun*).[53] They first read the passage

TABLE 2.
Singing Frequency

	Young			Middle-aged			Older			Total		
Singing Frequency	N Men	N Women	Mean Age ± SD	N Men	N Women	Mean Age ± SD	N Men	N Women	Mean Age ± SD	N Men	N Women	Mean Age ± SD
Never	7	5	29.17 ± 6.29	5	8	55.92 ± 8.26	4	10	74.64 ± 6.12	16	23	54.41 ± 19.97
Occasional (at least once a week)	3	5	27 ± 3.25	3	5	54.5 ± 8.05	1	1	73.5 ± 6.36	7	11	44.39 ± 17.99
Frequent (everyday)	2	4	28.33 ± 4.84	1	4	57 ± 7.91	2	2	76.75 ± 11.09	5	10	50.8 ± 21.8

silently and then they read it aloud in a "natural" way (ie, no acting) at their habitual pitch and amplitude levels.

Voice analyses

The recordings were analyzed with *Praat* software (version 5.3.39; Amsterdam, The Netherlands).[54] The acoustical parameters used in this study are detailed in Table 3. For the vowel /a/, 1-second interval taken in the middle part of the second, third, and fourth vowels were selected to ensure that measurements were made on a stable portion of the vowel. The first vowel was used to adjust the gain to prevent saturation of the recording; it was therefore not included in the analysis. The selected vowels were segmented manually. An automated procedure was then created to select the middle part of each sound for each participant, which was visually inspected to validate f0 tracking. Distortion in the vowel recordings rendered the vowel unusable for seven participants; these were excluded from the analyses. The remaining 195 vowels were analyzed (65 participants × three vowels/participant). f0 minimum, f0 maximum, f0 mean, and f0 SD; mean amplitude and amplitude SD; and jitter, shimmer, and HNR values were extracted automatically for the three productions of the vowel /a/, and an average was calculated for each participant. As absolute jitter has been shown to be influenced by mean f0,[55] here we calculated jitter local (ie, a f0 normalized jitter index, calculated as a percentage of f0) instead of absolute jitter.

For the standardized reading passage, the visible f0 was extracted from the samples one at a time. The pitch settings were adjusted manually to make sure we analyzed the frequencies of

TABLE 3.
Acoustic Measures Extracted With *Praat*, Along With the Windowing and Thresholds Used to Set Internal *Praat* Parameters in the Scripts

Measure	Definition	Specific Internal *Praat* Parameters	
Minimum f0 (Hz)	Minimum fundamental frequency (ie, number of glottic cycles per second)	<u>To pitch:</u> Time step: 0.0001 s Pitch floor: 75 Hz (men), 150 Hz (women) Pitch ceiling: 300 Hz (men), 400 Hz (women)	Time range: 0 to 0 (=all), Unit: Hertz, Interpolation: Parabolic
Maximum f0 (Hz)	Maximum fundamental frequency		Time range: 0 to 0 (=all), Unit: Hertz, Interpolation: Parabolic
Mean f0 (Hz)	Mean fundamental frequency		Time range: 0 to 0 (=all), Unit: Hertz
F0 SD (Hz)	Fundamental frequency standard deviation		Time range: 0 to 0 (=all), Unit: Hertz
Mean amplitude (dB)	Mean sound pressure level	<u>To intensity:</u> Minimum pitch: min Time step: 0 (=auto) Substract mean: yes	Time range: 0 to 0 (=all), Averaging method: dB
Amplitude SD (dB)	Sound pressure level standard deviation		Time range: 0 to 0 (=all)
Jitter local (%)	Absolute mean difference between consecutive periods, divided by the average period	Time range: 0 to 0 (=all) Shortest period: 0.0001 s Longest period: 0.02 s Maximum period factor: 1.3	
Shimmer local (dB)	Average absolute base-10 logarithm of the difference between the amplitudes of consecutive periods, multiplied by 20	Time range: 0 to 0 (=all) Shortest period: 0.0001 s Longest period: 0.02 s Maximum period factor: 1.3 Maximum amplitude factor: 1.6	
Harmonic-to-noise ratio (HNR, dB)	Degree of acoustic periodicity, ie, the ratio between periodic (vocal fold vibration) and aperiodic (glottal noise) voice components (harmonicity of the voiced parts only)	Time step (s): 0.01 Minimum pitch: 75 Hz (men), 150 Hz (women) Silence threshold: 0.1 Periods per window: 1.0 Mean harmonicity: time range: 0 to 0 (=all)	
SFF (Hz)	Mean fundamental frequency in speech	<u>To pitch:</u> Time step: 0.0001 s Pitch floor: from 50 Hz (men), 100 Hz (women) Pitch ceiling: under 300 Hz (men), and 450 Hz (women)	Time range: 0 to 0 (=all), Unit: hertz
SFF SD (Hz and semitones)	Standard deviation of the fundamental frequency in speech		Time range: 0 to 0 (=all), Unit: semitone or hertz

interest in relation with the f0 of each participant. No participant was excluded from this analysis. The range of frequencies selected was representative of each participant's speaking range. It varied in a range from 50 Hz to 300 Hz for men and from 100 Hz to 450 Hz for women. SD of the SFF was calculated in semitones (st) and in hertz.

Statistical analyses

All data were analyzed using *SPSS Statistics* 23 (IBM Armonk, NY). Acoustical measures (for sustained vowel: f0 minimum, f0 maximum, f0 mean, and f0 SD; mean amplitude and amplitude SD; jitter, shimmer, and HNR; and for propositional speech: SFF and SFF SD [Hz and st]) were used as the dependent measures. Outliers, defined as values that were three median absolute deviations away from the median of each acoustical measure in each group (gender and age grouping), were removed from the statistical analyses. After excluding outliers, the number of participants included in the analyses for each acoustical measure was as follows: f0 minimum (N = 58), f0 maximum (N = 58), f0 mean (58), and f0 SD (N = 62); mean amplitude (N = 55) and amplitude SD (N = 59); jitter (N = 56), shimmer (N = 57), and HNR (N = 53); and SFF (N = 67), SFF SD (Hz) (N = 67), and SFF SD (st) (N = 61). For all statistical procedures, a criteria of $\alpha = .05$ was used to establish significance. A false discovery rate (FDR) correction was applied on all *post hoc* analyses.[56] In the statistical analyses described below, age was used both as a categorical and as a continuous independent variable. It was used as a categorical variable in the analyses of variance (ANOVAs), in which participants were divided into three age groups (young, middle-aged, and old). In the moderation analyses, age was used as a continuous variable and was mean centered before the analyses to allow for easier interpretation of the results.[57]

Effect of age on voice acoustics

To assess age differences on voice acoustics, a series of FDR-corrected (FDR per sex: i = 12, q = .05) one-factor ANOVAs were conducted on the acoustical measures (f0 minimum, f0 maximum, f0 mean, f0 SD, mean amplitude, amplitude SD, jitter, shimmer, HNR, SFF mean, SFF SD [Hz], and SFF SD [st]) with age as categorical between-subject factor (three levels: 20–39, 40–65, 66–93 years). Men and women were analyzed separately. For the ANOVAs, measures of effect sizes are provided in the form of partial eta squared (η_p^2), which are reported for all main effects and interactions. FDR-corrected *post hoc* tests were conducted where appropriate. When comparing two means, we report effect sizes in the form of Cohen *d* statistics.

Effect of singing on the relationship between age and voice acoustics

To determine whether singing moderated the effect of age on acoustic measures, a conceptual model was developed (Figure 1). In this model, age affects voice acoustics, and this effect is moderated by singing frequency. This conceptual model was tested in an operative framework, ie, a moderation analysis. The moderation analyses were performed separately for each acoustic measure, for a total of 12 moderation analyses. Moderation and

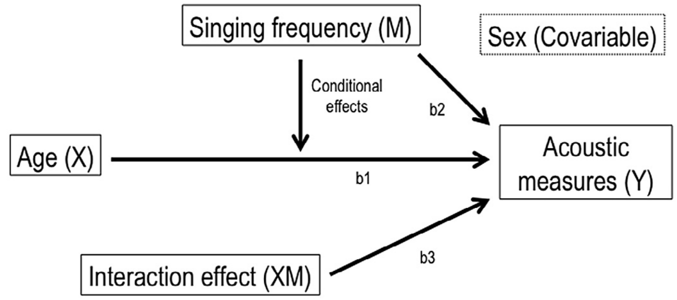

FIGURE 1. Conceptual moderation model used to uncover the moderating effect of singing frequency on the relationship between age and voice acoustics.

mediation analyses allow researchers to examine the mechanisms by which variables affect each other.[58–61] Moderation analyses estimate path coefficients in a single moderator model and generate bootstrap confidence intervals for the direct effect of X on Y conditional to a moderator (M). In the present moderation model, the dependent (Y) variable was the voice acoustic measures, whereas the independent (X) variable was the mean-centered continuous variable age. Sex was included in the model as a covariate. Singing frequency was used as the categorical moderator (M). For each analysis, four values are obtained (b1, b2, b3, and the conditional effect of X on Y through M). B1 represents the conditional effect of X on Y at M = 0 (people who do not sing). B2 represents the conditional effect of M on Y at X = 0 (where 0 is the mean age of the sample). B3 represents the interaction effect between X and M on Y. The conditional effect estimates how much the difference in Y between two cases that differ by a unit on X changes as M changes by one unit, in other words, it evaluates whether the effect of X on Y depends on M.

The moderation analyses were conducted using the PROCESS macro (model #1) for *SPSS* (http://www.processmacro.org/index.html).[57,61,62] A bootstrapping approach was used to test for the significance of the indirect effects[59] ($P = 0.05$, using bias-corrected bootstrapping with 10,000 samples). Bootstrapping involves the repeated extraction of samples, with replacement, from a dataset and the estimation of the indirect effect in each resampled dataset. From the tables generated by PROCESS, we created graphs that illustrate the extent to which the association between age and voice depends on singing frequency.

RESULTS

Associations between age and voice acoustics

Male voice

For men, a significant main effect of age was found on only one acoustic measure, ie, f0 SD ($F_{(2,22)} = 13.31$, $P < 0.01$, $\eta_p^2 = 0.56$). We explored the main effect of age on f0 SD using *post hoc* analyses, which showed that older men had significantly higher values of f0 SD than middle-aged men ($t_{(12)} = 3.16$, $P < 0.01$, d = 1.72) and young adults ($t_{(16)} = 4.09$, $P < 0.01$, d = 2.45) (Figure 2A). No other effect was found.

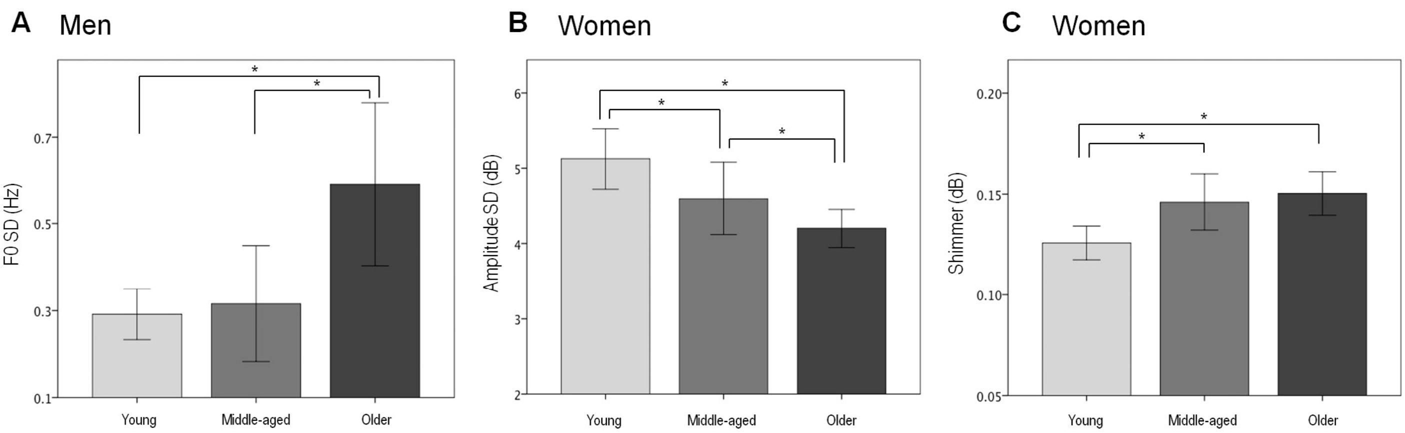

FIGURE 2. Age difference in voice stability. Voice f0 SD in men (**A**), amplitude SD in women (**B**), and shimmer in women (**C**) are displayed. Asterisks indicate significance at $P < 0.05$. Error bars represent the standard deviation of the mean.

Female voice

For women, significant main effects of age were found on most acoustic measures, including minimum f0 ($F_{(2,32)} = 11.98$, $P < 0.001$, $\eta_p^2 = 0.43$), maximum f0 ($F_{(2,33)} = 10.5$, $P < 0.001$, $\eta_p^2 = 0.39$), mean f0 ($F_{(2,33)} = 10.7$, $P < 0.001$, $\eta_p^2 = 0.39$), amplitude ($F_{(2,32)} = 6.56$, $P < 0.01$, $\eta_p^2 = 0.29$), amplitude SD ($F_{(2,32)} = 12.89$, $P < 0.001$, $\eta_p^2 = 0.45$), shimmer ($F_{(2,32)} = 13.07$, $P < 0.001$, $\eta_p^2 = 0.45$), and SFF ($F_{(2,42)} = 16.03$, $P < 0.001$, $\eta_p^2 = 0.44$). We explored the main effects of age using *post hoc* analyses, which showed that young women had higher minimum f0, maximum f0, and mean f0 values compared with middle-aged ($t_{(24)} = 2.55$, $P < 0.05$, d = 1; $t_{(25)} = 2.79$, $P < 0.05$, d = 1.08; and $t_{(25)} = 2.77$, $P < 0.05$, d = 1.07, respectively) and older women ($t_{(19)} = 4.76$, $P < 0.001$, d = 2.34; $t_{(19)} = 4.66$, $P < 0.001$, d = 2.29; and $t_{(19)} = 4.71$, $P < 0.001$, d = 2.32, respectively) (Figure 4A). Older women also had lower minimum and mean f0 values compared with middle-aged women ($t_{(21)} = 3.19$, $P < 0.01$, d = 1.33; and $t_{(22)} = 2.11$, $P < 0.05$, d = 1, respectively). Older women had lower voice amplitude values compared with middle-aged ($t_{(23)} = 3.14$, $P < 0.01$, d = 1.25) and young women ($t_{(20)} = 2.67$, $P < 0.05$, d = 1.22) (Figure 3). The voice of young women also had higher amplitude SD values compared with the voice of middle-aged ($t_{(24)} = 2.96$, $P < 0.01$, d = 1.2) and older women ($t_{(18)} = 5.96$, $P < 0.001$, d = 2.8). Middle-aged women had higher amplitude SD values compared with older women ($t_{(22)} = 2.27$, $P < 0.05$, d = 1.06) (Figure 2B). Shimmer was higher for the older ($t_{(19)} = 5.75$, $P < 0.001$, d = 2.77) and the middle-aged groups ($t_{(23)} = 4.55$, $P < 0.001$, d = 2.1) than for the younger group (Figure 2C). Finally, the younger group had higher SFF values than the middle-aged group ($t_{(29)} = 4.72$, $P < 0.001$, d = 1.74) and the older group ($t_{(25)} = 5.54$, $P < 0.001$, d = 2.13) (Figure 4B).

Effect of singing on the relationship between age and voice acoustics

The conditional effect of age on voice (b1) was significant only for f0 SD (Figure 5). Age was associated with high f0 SD values (Table 4; age). As expected, most voice measures were affected by sex, with the exception of mean amplitude, jitter, and SFF SD (st) (Table 4; sex). Interestingly, singing frequency had a significant conditional effect on many voice measures (b2) (Figure 5): it was associated with high f0 minimum, f0 maximum, and f0 mean values; and high amplitude SD values (Table 4; singing frequency). The interaction between age and singing frequency (b3) significantly influenced the same acoustic measures, plus shimmer (Figure 5). Specifically, the interaction between age and singing frequency was associated with low f0 minimum, f0 maximum, and f0 mean values; low amplitude SD values; and high shimmer values (Table 4; interaction effect).

In our conceptual framework, singing frequency was hypothesized to moderate the relationship between age and voice acoustics. As was expected, the effect of age on most voice measures was affected by singing frequency (Figure 5; conditional effect). In particular, more frequent singing was associated with low f0 minimum, f0 maximum, and f0 mean values; low amplitude SD values; high shimmer values; and low SFF values. No singing was associated with high f0 SD values, whereas occasional singing was associated with low mean amplitude values (Table 4; conditional effects). Some of the conditional effects

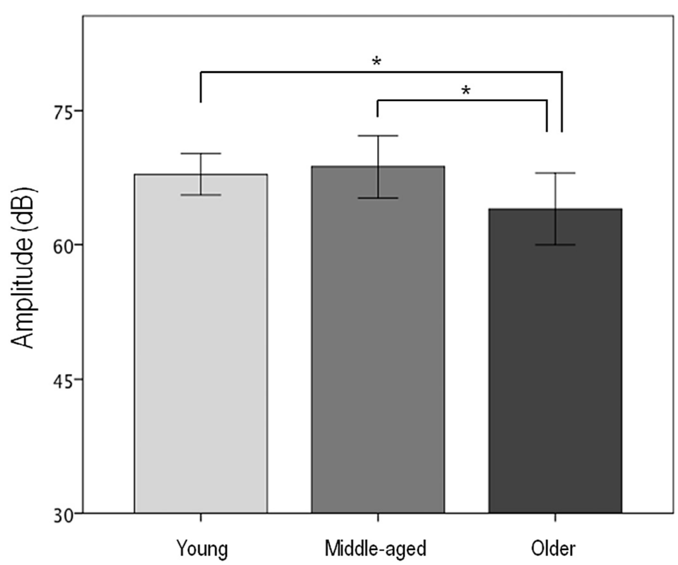

FIGURE 3. Age difference in mean voice amplitude in women. Asterisks indicate significance at $P < 0.05$. Error bars represent the standard deviation of the mean.

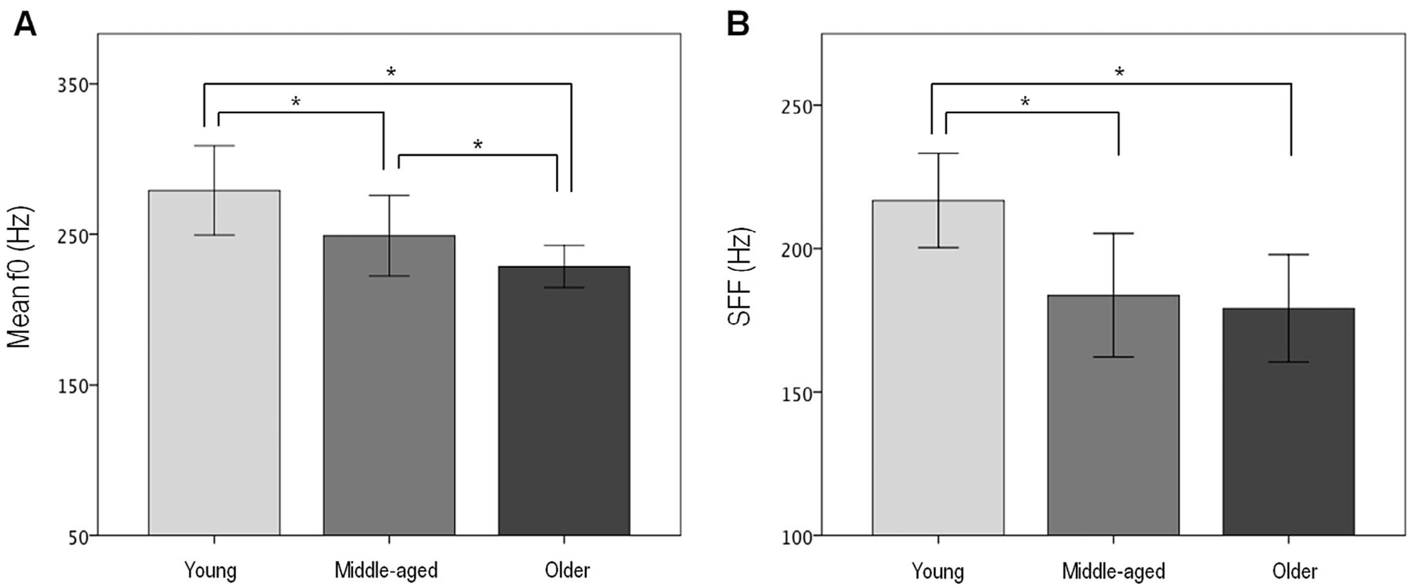

FIGURE 4. Age differences in mean f0 (**A**) and SFF (**B**) for women. Asterisks indicate significance at $P < 0.05$. Error bars represent the standard deviation of the mean.

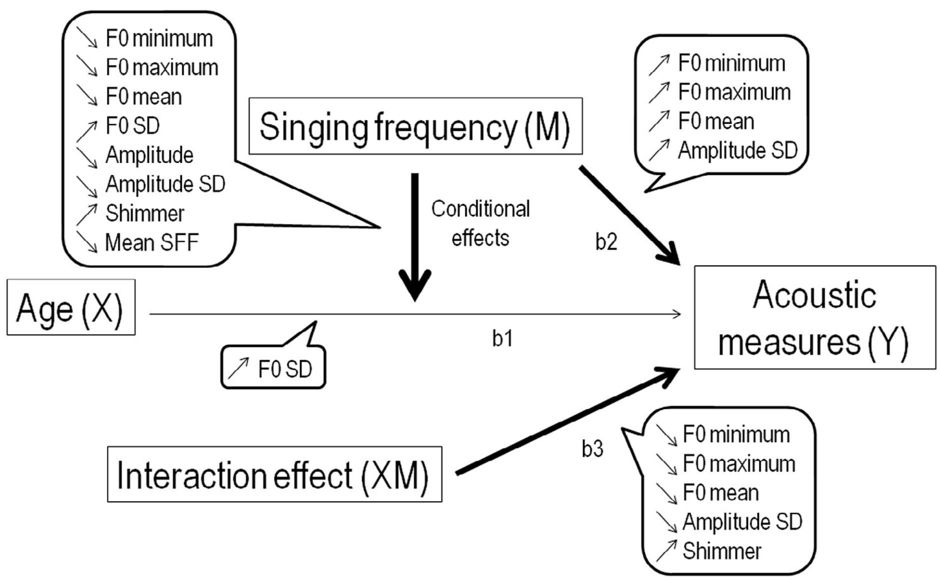

FIGURE 5. Results of the moderation analyses. The relationship between age and voice acoustic measures was moderated by singing frequency. The direction of the arrows indicates the direction of the effects. From the left: Age was associated with high f0 SD (b1). There was a direct effect of singing frequency on minimum, maximum, mean f0, and amplitude SD (b2). The interaction between age and singing frequency (XM) was associated with low minimum, maximum, and mean f0; low amplitude SD; and high shimmer (b3). Finally, there was a conditional effect of singing frequency on the relationship of age to voice acoustics whereby frequent singing was associated with low minimum, maximum, and mean f0; low amplitude SD; high shimmer; and low mean SFF. No singing was associated with high f0 SD, whereas occasional singing was associated with low mean amplitude.

of singing frequency suggest a positive effect of frequent singing on the aging voice. In particular, age was associated with higher f0 SD values in non-singers but not in occasional and frequent singers (Figure 6). Age was also associated with high amplitude SD values in non-singers but not in occasional or frequent singers (Figure 7).

For several measures, we observed that singing frequency (occasional and frequent) was associated with advantages in the young singers in terms of f0 minimum, f0 maximum, f0 mean, shimmer, and mean SFF. However, these advantages disappeared with age. Indeed, for these measures, the values observed in older non-singers were similar to those observed in occasional and frequent older singers. Of note, no effect on jitter and SFF SD (st) was found.

DISCUSSION

The goal of this study was to characterize the relationship between aging and voice production in two different contexts (production

TABLE 4.
Results of the Moderation Analyses. For Each of the Different Paths, the Linear Regression Coefficients (β) and Significance (*P*) Are Reported and Listed for Each Acoustical Measure

	Age (b1)		Singing Frequency (b2)		Interaction Effect (b3)		Sex		Conditional Effect	
Acoustic Measures	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*
F0 minimum	8.977	0.029	−0.156	0.441	−0.515	0.007	103.37	0.000	−0.879	0.000
F0 maximum	9.346	0.027	−0.208	0.318	−0.502	0.01	105.09	0.000	−0.905	0.000
F0 mean	9.447	0.025	−0.215	0.3	−0.497	0.011	104.27	0.000	−0.905	0.000
F0 SD	−0.068	0.088	0.005	0.007	−0.003	0.062	0.31	0.000	0.005	0.007
Mean amplitude	0.312	0.607	−0.037	0.211	−0.015	0.579	−1.341	0.162	−0.048	0.036
Amplitude SD	0.213	0.011	−0.001	0.726	−0.01	0.009	2.191	0.000	−0.016	0.000
Jitter	0.000	0.67	0.000	0.712	0.000	0.221	−0.000	0.233		
Shimmer	−0.003	0.176	0.000	0.964	0.000	0.005	−0.029	0.000	0.000	0.000
HNR	0.223	0.567	−0.024	0.173	0.014	0.439	4.251	0.000		
Mean SFF	0.13	0.965	−0.294	0.063	−0.256	0.082	83	0.000	−0.669	0.000
SFF (Hz)	0.879	0.428	−0.01	0.847	−0.006	0.918	11.503	0.000		
SFF SD (st)	0.003	0.936	0.001	0.631	0.001	0.762	0.105	0.398		

of a sustained vowel, and overt reading of a standardized passage) in adults with different singing habits. Our results show that aging has a significant impact on most acoustic measures of women's voice in both tasks. For men, only one significant effect of age was found on the f0 SD in the sustained vowel. Importantly, our results suggest that frequent voice singing can contribute to the maintenance of certain acoustic parameters from declining throughout aging. These results are detailed in the following paragraphs.

Voice aging

Our results show vastly different age effects on the voice of men and women. For men, only a significantly higher f0 SD was found in the sustained vowel task in older men than in middle-aged and young men, in line with a previous study.[29] No other significant age effects were found. This is surprising, given that several studies have reported significant age effects on these acoustical measures, in particular f0.[4,6,24,33,34] A previous study has reported that men in good physiological health have lower shimmer values than men in poor physiological health.[33] The authors observed that a better physiological health contributes

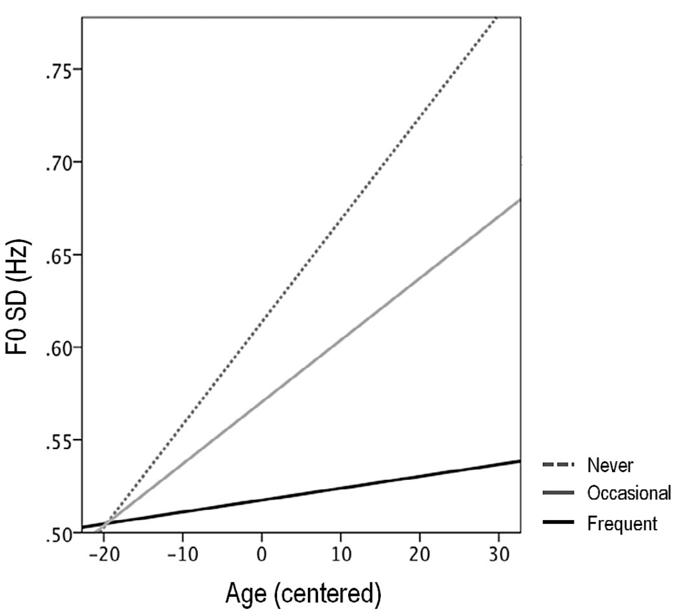

FIGURE 6. Conditional effects of singing frequency on the relationship between age (in years) and voice f0 SD. The variable age was mean centered to facilitate interpretation. A value of 0 thus refers to the mean age of the sample, which was 51 years. Negative values refer to participants younger than the mean, whereas positive values refer to older participants.

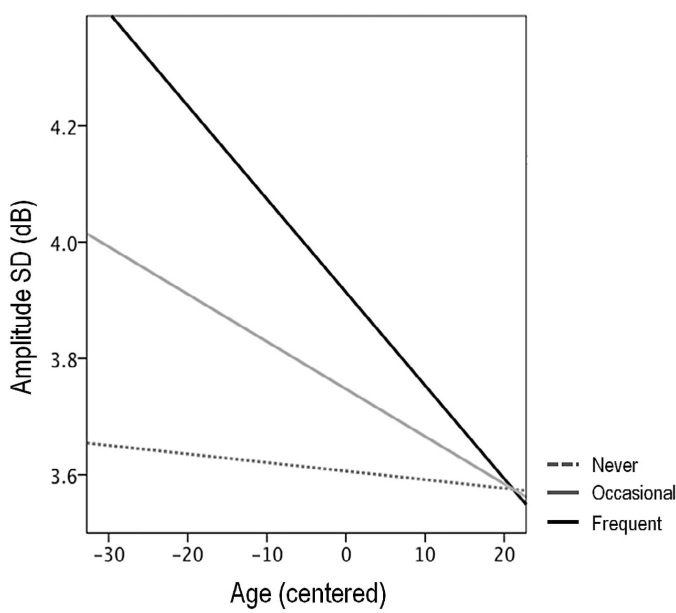

FIGURE 7. Conditional effects of singing frequency on the relationship between age (in years) and amplitude SD. The variable age was mean centered. A value of 0 thus refers to the mean age of the sample, which was 51 years. Negative values refer to participants younger than the mean, whereas positive values refer to older participants.

to a better voice control independent of age. It is possible that men in our study were in a better physiological condition than men in previous studies, and therefore aging had less effect on their voice. However, although participants in our study were all in good (self-reported) health, no objective measure of global health was taken. Additionally, our sample was not completely balanced in terms of gender with 30 men and 44 women. The lack of a health measure, and the relatively small and unbalanced sample, could have contributed to the differences found between men and women. In women, in contrast, we confirmed the significant decrease in f0 values with age.[4,21,24–27] We also observed a diminution of amplitude SD (ie, better control over amplitude variations) and an augmentation of shimmer with aging. Those results corroborate previous reports,[24,34] and may be related to physiological and hormonal changes that occur in aging such as vocal fold bowing and increased glottal gap.[1,10,13,20,63] Interestingly, we found no significant effect of aging on jitter values in men or in women. As mentioned in the introduction, jitter is the acoustic measure showing the least consistency across studies in the literature.[4,24,29–33] Interestingly, an effect of voice amplitude on jitter and shimmer measurements has been documented, with higher voice amplitude associated with more regular vocal fold vibration, and thus with reduced jitter values.[35,37] It is thus possible that age effects on jitter were attenuated in the present study because we controlled for voice amplitude during the recordings (80 dB SPL). When not given specific instructions and feedback about voice amplitude, older adults may speak with a softer and possibly less stable voice, which would lead to age differences, as shown in a previous work.[29] Taken together, our results show multifaceted impacts of age on the female voice and more circumscribed age effects on the male voice.

Singing and the aging voice

The present study aimed to investigate the potentially positive effect of singing on the normal aging of voice. Our general hypothesis was that singing would help enhance voice control and therefore reduce perturbations and variations in the acoustic voice signal. The most important finding of this study is that, to a certain extent, singing does protect the voice from the decline in stability associated with normal aging, at least within the age range that we studied (20–93 years). Consistent with this finding, a recent study involving younger and older Carnatic classical singers and non-singers reported significant effects of singing and age on several acoustic measures of the voice, including the highest f0 value reached using a crescendo method.[43] A previous study has shown that vocal function exercise (VFE) can help mitigate physiological changes occurring in aging in singers.[44] The impact of training was observed on a small population of aging community of choral singers and reflected by an improvement on maximum duration time, jitter, shimmer, and HNR measures. VFE is often used in clinical settings and by professional singers to strengthen laryngeal muscles and to facilitate efficient vocal fold vibration. VFE was also shown to widen phonation range in teachers,[64] and to improve noise and aerodynamic measures in young singers.[65]

A positive effect of singing on voice aging may result from different mechanisms, including better control of air pressure, vocal fold adduction, and laryngeal position, which helps maintain a good output-cost ratio (ie, ratio of the acoustic output amplitude to the stress imposed on the vocal folds during adduction). For instance, resonant voice, which is used by singers, has been shown to effectively and effortlessly convert the aerodynamic energy into acoustic energy.[66] Singers also learn to modify the configuration of their vocal tract to produce different pitch, timbre, and voice effects.[67,68] A tendency to produce different articulatory configurations has been reported for singers (ie, widening of the lips and the pharynx, jaw opening, and raising of the tongue dorsum).[68,69] Thus, singers' ability to finely control the shape of their vocal tract to obtain specific sounds may serve as a compensatory mechanism in aging. Furthermore, specific warm-ups are known to influence aerodynamic and electroglottographic measures in singers (ie, semi-occluded vocal tract as lip thrill and humming).[70] In sum, through regular exercises, singers learn to control respiratory, phonation, and resonance mechanisms to obtain stability of the vibration of the vocal folds effortlessly.[64,67–69]

However, it is important to point out that voice registers are not affected in the same way by singing training,[71] and that laryngeal control is not equivalent between singing techniques.[67] Moreover, a recent study found that different singing styles engaged laryngeal and pharyngeal structures in distinct manners and to different extents, and that rock singing seemed to be the style with the highest degree of both laryngeal and pharyngeal activity in healthy singers.[72] Yet a previous study indicated that rock singers who use growling voice and reinforced falsetto did not show any significant difference from pop singers for acoustic and perceptual assessment of speaking voice, and did not show any major vocal fold pathology.[73] Taken together, these findings suggest that singing can be used to help alleviate voice issues occurring through normal aging, although different singing styles may have distinct effects given that they engage laryngeal structures in distinct ways. Understanding the nature and extent of age-related voice decline, as well as the positive impact of specific vocal habits including singing, is key to developing new interventions to delay the onset of—and potentially prevent—these difficulties. The present study is a step toward that broad and important goal. Future research needs to clarify the parameters that most benefit from singing, and whether all types of singing have a similar positive effect.

Importantly, in the present study, we showed positive effects of singing on pitch and voice amplitude in frequent singers. This is consistent with a previous study in which Pizolato and colleagues[64] demonstrated, in a sample of 102 teachers, that voice exercises targeting amplitude and pitch (tongue or lip thrills) associated with vocal hygiene guidance can have an immediate impact on voice acoustics, but must be used regularly to maintain this effect. Hence, although the present study shows a beneficial effect of singing on the aging of several voice acoustic parameters, additional studies are needed to clarify the intensity and frequency of singing needed to obtain long-term positive effects on voice.

LIMITATIONS

The present study provides interesting new evidence on the positive effect of singing on the aging voice. Nevertheless, the study does present a few limitations including a cross-sectional design, the lack of an objective measure of global health, a small sample size, heterogeneity in singing habits in the sample, and a relatively rough characterization of singing frequency. Although our global sample included 72 adults, this sample was broken down in subgroups for the analyses, which comprised 20–26 participants each. Moreover, because of a limited sample size with heterogeneous singing habits, we could not control for the kind of vocal training that participants received and for the singing style that participants performed. However, weekly singing frequency, which could be studied, proved to be an important moderating factor for voice aging. Yet a more detailed description of the participants' singing habits could help clarify the effect of singing on voice aging. For example, knowing the number of minutes each participant sang when they sang could reveal whether singing for a longer time but less frequently rather that singing often but briefly is more beneficial. Finally, because of the cross-sectional nature of the study, we cannot exclude that other factors related to singing habits may contribute to explaining the moderating effect of singing frequency on the aging of voice. Further studies are needed with large sample sizes, more controlled singing habits, and ideally a longitudinal design. Nevertheless, we do believe that the present findings are important as they pave the way to further, more detailed investigations of the positive effect of singing on voice aging.

CONCLUSIONS

This study contributes to current understanding of the normal aging of the human voice and provides new and important information on the relation between singing frequency and voice aging. Our results suggest that frequent singing can moderate negative age-related effects on voice, in particular in terms of the stability of pitch and amplitude, two important voice parameters that can significantly affect the effectiveness of communication. Based on our results, we hypothesize that singing, which represents a form of muscular training, helps maintain muscular strength and control over voice stability even in the presence of physiological changes that appear in aging. Although additional research is needed to guide clinical practice, these results are among the first to provide empirical evidence that singing exercises could be a low-cost alternative, or a complement, to traditional voice therapy, which could be self-administered at home.

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