Hyposalivation Affecting Womens' Voice

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Summary: Objectives. Balanced hydration is crucial for optimal physiological function, whereas hypohydration may cause adverse effects. Like many other organs, the larynx is negatively affected by hypohydration, potentially affecting voice production. Therefore, the purpose of this study was to examine voice properties in women diagnosed with dry-mouth.

Methods. Twenty-four women diagnosed with hyposalivation and 24 age-matched controls were recruited. All participants underwent three sialometry tests for quantifying oral-dryness. These tests were conducted in three conditions: after 2-hour fasting, after gustatory salivary stimulation and after drinking water. After each sialometry, participants were recorded while producing the vowels /a/ and /i/, and during a standardized reading task. A basic set of acoustic measures was extracted from these recordings. Self-evaluation of voice was performed using the VHI-10 questionnaire; and listeners' perception of the voice was performed by five professional judges who rated the recordings perceptually, using the GRBAS scale.

Results. Significant group differences were found in fundamental frequency and jitter, but not in shimmer and noise-to-harmonic ratio (corrected $P < 0.05$). The participants in the hyposalivation group exhibited higher scores on the VHI-10 questionnaire compared to the control group ($P = 0.002$), and the judges perceptually rated their voices higher on the Grade and Roughness scales ($0.03 \leq P \leq 0.04$). In contrast with the significant group differences, no significant differences were found between the three study conditions.

Conclusions. Women suffering from oral-dryness were shown to exhibit degradation in voice quality, evident in both acoustic, perceptual and self-evaluation measures. However, in this paradigm, short-term superficial hydration was not shown to elicit a significant improvement in voice properties. These findings highlight the importance of consistent oral-hydration for voice, especially among people suffering from hyposalivation.

Key Words: Hyposalivation−Hydration−Oral-dryness−Voice−Xerostomia.

INTRODUCTION

Water is essential for the existence and development of life. The human body consists of 75% water in infants, with a gradual reduction to 55% in elderly.[1] Balanced hydration is crucial for optimal physiological function, whereas hypohydration may cause adverse effects, such as accelerated heart rate, decreased blood volume, and elevated body temperature,[2,3] as well as a decrease in cognitive performance, memory function, and mood.[4,5] Like many other organs, the larynx and the vocal folds are negatively affected by hypohydration, potentially also affecting voice production. Previous research has shown that Phonation Threshold Pressure, for example, increases during dehydration, in addition to speakers' subjective reports on vocal effort and reduced voice quality.[6] Other studies have supported these findings acoustically, and reported higher values of perturbation measures (eg, jitter, shimmer) during phonation in specific dry air conditions.[7,8]

Hydration may be either systemic or superficial. *Systemic* hydration refers to fluids contained within the cells and tissues, which constitute two-thirds of the total fluid volume in the body. *Superficial* hydration, on the other hand, refers to the fluids that envelop the external layers of tissues. Accordingly, the larynx, and specifically the vocal folds, may be affected by both superficial and systemic hydration (or dehydration).[9−13] Hence, increasing water consumption is commonly recommended for voice users, in addition to increasing ambient humidity or inhalation of water vapor.[9]

Interestingly, studies that probed specific populations have questioned the clinical impact of hydration on the voice mechanism, and suggested that dehydration does not necessarily affect voice per se.[14−16] This seeming controversy may be attributed to various methodological limitations, such as the differences in the operational definition of dehydration, inconsistencies in the procedure used for assessing hydration levels, differences in study populations, sample size, and the lack of control groups. Along this line, a thorough historic review of the literature sought to unveil the source and the scientific rationale for the common clinical advice of drinking eight glasses of water a day.[10] This review has questioned the merit of this common recommendation, and concluded that it should be revisited and scientifically examined. Nonetheless, despite the limited empirical evidence for the specific importance of hydration for adequate voice production, clinicians typically recommend a daily consumption of eight glasses of water.[11,12]

Systemic dehydration is a common cause of xerostomia (ie, subjective sensation of dry mouth) and hyposalivation, especially in elderly people. This is attributed to various factors. Systemic dehydration may develop due to changes in the water and salt balance caused by diseases, such as uncontrolled diabetes and renal diseases, or by medications, such as diuretics. It has been shown that dehydration is

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associated with decreased parotid saliva flow rates and that these changes may be age-independent in healthy adults.[13] Research show that approximately 50% of the stimulated whole saliva is derived from the parotid glands[17]; hence, a decrease in stimulated whole saliva may be an indicator of systemic dehydration.

The mucosa of the oral cavity, pharynx, and larynx are contiguous and therefore, affected by similar factors.[14] Previous studies that assessed the influence of superficial dehydration of the vocal folds on voice characteristics used techniques of mouth breathing or inhalation of dried air to induce superficial dehydration of the vocal folds.[15] Accordingly, people experiencing long periods of hyposalivation and dry-mouth may represent a constant state of superficial vocal folds dehydration. Despite the importance of directly measuring superficial hydration of the vocal folds, it is challenging, and for the most parts − impractical. In contrast, measuring salivary secretion rate by a sialometry test is a reliable, noninvasive, and relatively simple procedure.[18–21]

Sialometry is a clinical test, in which the amount of secreted saliva is measured over a given time.[16] Although normal salivary flow varies between people, individual saliva flow rate remains rather constant.[22] Hence, measuring salivary flow rate is considered a reliable measure of daily oral hydration. Collecting whole saliva (ie, the combined secretion of the major and minor salivary glands, as well as the gingival crevicular fluid) is the preferred method for evaluating overall mouth dryness and associated systemic disease. In contrast, collecting glandular-derived saliva (ie, saliva secretion from the parotid, submandibular, sublingual and/or the minor salivary glands) is more useful for the diagnosis of the specific metabolic status of those glands. Furthermore, collecting whole saliva is an easier and faster technique, that requires simple and low-cost equipment, and as such − it is the most commonly used method applied to evaluate mouth dryness.[17]

The sialometry test includes measurement of unstimulated and stimulated saliva secretion; since assessment of both conditions is essential for the diagnosis of hyposalivation. The unstimulated secretion is substantially influenced by the time of day, seasonal changes, recent oral stimulations, body position, and changes in light and temperature. Therefore, studies usually attempt to control for these variables when possible. The most important variables that should be controlled for during sialometry are time of the day and duration of collection procedure (minimum of 5 minutes is recommended).[17] The accepted normal salivary flow rate of unstimulated whole saliva is >0.2 mL/min, while a flow rate of <0.1 mL/min is considered very low.[17,23]

Four different sialometric collection techniques of *unstimulated* (resting) whole saliva are described in the literature. These include (1) the draining method, (2) the spitting method, (3) the suction method, and (4) the swab technique; all of which provide similar results.[17] In addition, for the purpose of examining *stimulated* whole saliva secretion, two methods are used clinically and for research purposes: (1) mastication and (2) gustatory stimulation with a citric acid solution. After the stimulation, whole saliva is collected, here too, using the same techniques as the unstimulated saliva. The accepted normal salivary flow rate of stimulated whole saliva is >1.0 mL/min, whereas flow rates of <0.7 or <0.5 mL/min are considered the low limit of the normal range by most investigators.[17]

While the impact of hyposalivation on various physiological systems has been examined extensively, the research on the specific effects of hyposalivation on voice is limited and controversial. Rho et al,[24] for example, exposed 20 healthy adults to a controlled oral-dryness condition, and reported a reduction in voice quality, which was evident acoustically and perceptually. Nonetheless, inspection of their data reveals that only a limited number of measures in their study have yielded statistically significant effects. A few other studies have attempted to examine the relationship between oral-dryness and voice production. These studies have shown that oral-dryness caused by fasting (ie, short-term systemic dehydration),[25] or by Sjögren's syndrome (ie, long-term superficial dehydration)[18,26] may affect voice production acoustically or perceptually. Yet, results have been inconsistent and sometimes contradictory, indicating the need for further research on this topic.[27–29]

The present study aims to examine the relationship between chronic hyposalivation and the voice (phonation). Considering the methodological limitations of previous studies, it was deemed necessary to use the standard clinical definition of hyposalivation, and to compare voices of patients diagnosed with hyposalivation to voices obtained from healthy controls. Because hyposalivation is markedly more prevalent in women than in men,[17,19] and due to the differences in the acoustic properties of the voice between sexes, the present study examined only women. Furthermore, in order to adhere to conventional clinical procedures and obtain a reliable representation of the patients' condition, it was decided to examine all participants in three controlled conditions: after refraining from eating and drinking for 2 hours (rest condition), following salivary stimulation and after water intake.

METHODS

Participants

This study was approved by the Helsinki committee of Maccabi Healthcare Services (#0101-17-BBL), and by the Tel Aviv University ethics committee.

All female patients referred to an oral medicine specialist (O.G-K) due to a complaint of subjective xerostomia, between June 2018 and January 2019, and who were scheduled for a sialometry test as part of their clinical examination, were offered to participate in the study. Thirty-three of them volunteered for the study. Prior to enrollment in the study, all potential participants completed and signed an informed consent form and an anamnesis questionnaire, to rule out known pathologies or conditions that could potentially affect voice (eg, smoking, speech or hearing impediments, known laryngeal pathologies, or other relevant medical history), apart from symptoms of dry-mouth or

hyposalivation. Based on the responses to the questionnaire, one woman was excluded due to unilateral vocal fold paralysis. Of the 32 patients remaining, three failed to qualify based on sialometry results. In addition, five patients did not complete the study protocol. Consequently, the study group consisted of 24 women with a mean age of 64.8 years (SD = 9.9), who complained on xerostomia for an average duration of 2.9 years (range: 1 month to 10 years), and were clinically diagnosed with hyposalivation. Clinical diagnostic criteria included observable signs of dry mouth (eg, dry sticky oral mucosa and lack of saliva pooling in the floor of mouth), and sialometry test results (whole saliva flow rate without stimulation <0.2 mL/min).

An age-matched group of 24 healthy women, with a mean age of 65.3 (SD = 9.5), who denied a subjective feeling of dry mouth, and also qualified for the clinical diagnosis of normal whole saliva flow rate at rest (>0.2 mL/min) was recruited for the study, and served as control. Like the study group, all women in the control group denied swallowing difficulties, laryngeal diseases, smoking, alcohol consumption, occupation requiring voice effort, and/or a history of voice therapy.

Procedures

Experimental conditions

All participants underwent a sialometry test followed by a voice recording in three conditions: (1) after refraining from eating and drinking for 2 hours (rest condition), (2) after gustatory salivary stimulation, and (3) after drinking one cup of water. The first two conditions adhere to the clinical protocol of the sialometry test,[16] whereas the third condition was added to the protocol for the purpose of this study.

The rationale for performing the initial examination after 2-hour fasting was to standardize a baseline (rest) condition. This was intended to imitate the participants' routine superficial hydration status of the oral cavity, without inducing systemic dehydration. To that end, participants were instructed to fast for 2 hours before the first recording (ie, refrain from eating, chewing a gum, drinking or brushing their teeth).[17]

The second condition represents the superficial hydration status of the oral cavity following gustatory salivary stimulation, as shown for example during daily eating. This condition was expected to facilitate an increase in superficial hydration. This procedure is usually preferred for collecting stimulated whole saliva, as previous research has shown that gustatory stimulation generally produces a greater increase in salivary flow rate than masticatory stimulation.[17]

The third condition was intended to examine the effect of oral superficial hydration induced by drinking water. As the sialometry exam and the recording session were conducted immediately after drinking the water, this condition was viewed as representing a controlled oral superficial hydration condition, but not as affecting the systemic hydration status.

Sialometry exams

All examinations were conducted between 8 and 11 a.m., as recommended for routine saliva collecting,[17] while maintaining similar light and temperature conditions.[17,20] For this test, participants were instructed to sit quietly in an upright position with their head tilted down a little. They were instructed to avoid swallowing, talking or changing their body position during the saliva collection. Then, they swallowed once, before initiation of the test. Following, the participants were asked to expectorate periodically (when feeling the need to) all accumulated saliva into a 10 mL disposable plastic graduated syringe (with its tip plugged with dental wax) for exactly 5 minutes. During saliva collection, the participants were monitored by the Oral Medicine clinic's professional staff to insure all requirements were met. The volume of the collected saliva was read from the markings on the syringe, and divided by 5, to determine salivary flow rate (mL/min). Salivary flow rate of <0.2 mL/min was considered hyposalivation, as accepted,[17] and was an inclusion criteria for the "hyposalivation" study group.

For the second sialometry test, all participants underwent tongue local gustatory stimulation, using a cotton applicator soaked with citric acid to stimulate saliva flow. The citric acid was applied on the participant's dorsolateral borders of the tongue four times repeatedly, in 15 seconds intervals, for 1 minute.[16] During this time, participants were allowed to swallow. After the completion of the stimulation, the participants were instructed to stop swallowing, and produce the second sialometry sample for 5 minutes.

Finally, prior to the third sialometry test, the participants were instructed to drink a cup of water (180 mL). Then the third sialometry sample was collected.

Recordings

After completing each of the three sialometry tests, participants were recorded while producing six repetitions of the vowels /a/ and /i/, in a random order, using a comfortable pitch and intensity level. Following, the participants read aloud a single paragraph from a standardized phonemically balanced Hebrew reading passage.[21]

Audio recordings were performed in a quiet room, using a Sennheiser PC20 headset microphone placed 7 cm from the corner of the speaker's mouth. The signal from microphone was directed to a computer using an external Xenyx 302 USB sound card. The *GoldWave*^{TM} recording and editing software (v6.27) was used for recording and normalizing the signal.

Self-perceptual evaluation

Prior to the first sialometry exam, all participants filled in the Hebrew version of the VHI-10 questionnaire,[30] as a self-evaluation measure of voice.

Perceptual evaluation

Perceptual evaluation of the participants' voice was performed by five speech-language pathologists who specialize in voice. To that end, the five observers listened to samples of each subject's voice. These samples consisted of the second production of the vowels /a/ and /i/, and a

randomly selected sentence from the reading passage that were recorded during the rest condition (ie, after 2-hour fasting). These recording were selected for the listening task as a representation of the participants' baseline voice, prior to the manipulations performed during the study. The listening task was performed individually in a quiet room using headphones, at a comfortable intensity level, and ratings were performed using the GRBAS scale.[31]

Acoustic analysis

Acoustic analyses were performed using the *Praat software* (ver. 6.1.07),[32] after manual inspection of the signal and correction of octave errors. Acoustic measures analyzed from the reading samples consisted of amplitude-range and fundamental-frequency (F0) range. These two measures were included as a general representation of the speakers' voice dynamics during speech (specifically in the present study, during reading).[33] Amplitude-range was calculated by subtracting the minimum amplitude value from the maximum amplitude value within each sentence. Then, a mean value was calculated for each speaker, within each of the three conditions. Similarly, F0-range was calculated by subtracting the minimum F0 value from the maximum value within each sentence. Then, a mean value was calculated for each speaker, within each of the three study conditions.

Acoustic measures analyzed from the isolated vowels consisted of F0, jitter, shimmer, and noise-to-harmonic ratio (NHR). Analyses of the isolated vowels were performed on 1-second segments extracted from the middle section (ie, relatively steady state) of each production. Accordingly, the onset and offset of each isolated vowel were not included in the analysis.

Evaluation of intrajudge reliability for the acoustic measurements was performed on the recordings of five speakers, randomly selected, whose recordings were analyzed again after 3 months by the same experimenters. Strong and significant correlations were found between the repeated measurements of all acoustic parameters ($0.98 < r < 0.99$, $P < 0.001$).

Statistical analysis

Statistical analyses were performed using *SPSS* Ver. 25 (IBM©, SPSS©, 2017). The research variables were described using means and standard deviations. *t* Tests and multivariate analyses-of-variance were used to examine group and condition differences, as well as their interactions, for the dependent variables. To avoid inflation of Type I error, an FDR correction was used,[27] with experiment-wise error set at 0.10.

RESULTS

This study examined differences in voice characteristics between women with and without hyposalivation, and also examined the association between oral superficial hydration and voice. Table 1 summarizes group mean values of all examined measures, arranged by categories (ie, physiological, acoustic, self-evaluation, and perceptual).

Sialometry

Prior to examining the voice characteristics, it was necessary to confirm that the two study groups were, indeed, different in their salivary discharge rates, based on the sialometry values. Data in Table 1 demonstrate that the control group exhibited higher saliva secretion rates in all conditions, compared to the study group. As shown, the control group exhibited a mean unstimulated salivary flow rate that was above the clinical threshold of 0.2 mL/min., which is the diagnostic criterion for hyposalivation.[17] The study group, on the other hand, exhibited a mean unstimulated salivary flow rate of <0.1 mL/min, which is characterized as significant hyposalivation.[23]

Figure 1 illustrates the differences in salivary flow rate between the two groups in the three study conditions. As shown, in both groups, the mean salivary flow rate was the lowest at rest (after refraining from eating and drinking for 2 hours) and the highest after gustatory stimulation. An analysis-of-variance (ANOVA) in which Group and Conditions were defined as the independent variables, and sialometry values as the dependent variable, confirmed a significant main effect for Group [$F_{(1,46)} = 32.71$, $P < 0.001$], and a significant main effect for Condition [$F_{(2,46)} = 81.58$, $P < 0.001$]. Contrast analysis revealed significant differences among all three study conditions (rest, citric acid, water intake) ($P < 0.001$) and a significant Group X Condition interaction [$F_{(2,46)} = 4.91$, $P = 0.009$].

Acoustic analyses

Acoustic analyses of the sustained phonations of the vowels /a/ and /i/ revealed consistent results. The women in the hyposalivation group exhibited lower fundamental frequency (F0) than the women in the control group. These group differences were statistically significant using an ANOVA, which revealed a significant main effect for Group for both vowels /a/ and /i/ [$F_{(1,46)} = 5.43$, $P = 0.02$; $F_{(1,46)} = 7.59$, $P = 0.008$, respectively]. No significant differences for F0 were found among the three experimental conditions for either vowel [$F_{(2,46)} = 1.01$, $P = 0.36$; $F_{(2,46)} = 0.72$, $P = 0.48$, for /a/ and /i/, respectively]. In addition, no significant Group X Condition was found for F0 in the vowel /a/ or /i/ [$F_{(2,46)} = 0.53$, $P = 0.58$; $F_{(2,46)} = 0.42$, $P = 0.65$, respectively].

The women in the hyposalivation group exhibited consistently higher jitter values than those of the women in the control group. A significant main effect for Group was found for both vowels /a/ and /i/ [$F_{(1,46)} = 8.48$, $P = 0.006$; $F_{(1,46)} = 10.14$, $P = 0.003$, respectively]. Similar to the results of the F0 measure, no significant differences for jitter were found among the three experimental conditions for either vowel [$F_{(2,46)} = 2.46$, $P = 0.10$; $F_{(2,46)} = 0.59$, $P = 0.55$, for /a/ and /i/, respectively], nor a significant Group X Condition interaction [$F_{(2,46)} = 1.95$, $P = 0.14$; $F_{(2,46)} = 0.35$, $P = 0.70$, for /a/ and /i/, respectively].

No significant main effects for Group or Condition, nor a significant Group X Condition interaction, were found for the other measures extracted from the isolated vowels

TABLE 1.
Mean Values and Standard Deviations (in Parentheses) Obtained From the Two Groups for the Examined Physiological, Acoustic, Self-evaluation and Perceptual Measures

		Hyposalivation Group			Control Group		
Category	Measure	Rest	Citric Acid	Water Intake	Rest	Citric Acid	Water Intake
Physiologic	Sialometry (mL/min.)*	0.08 (0.06)	0.39 (0.24)	0.19 (0.13)	0.31 (0.10)	0.49 (0.14)	0.42 (0.14)
Acoustic	F0 /a/ (Hz)*	156.71 (29.38)	157.27 (27.91)	157.57 (30.04)	165.50 (28.32)	169.32 (31.08)	170.03 (27.63)
	Jitter /a/ (%)*	1.40 (2.13)	0.78 (0.88)	0.77 (0.65)	0.44 (0.23)	0.43 (0.23)	0.40 (0.20)
	Shimmer /a/ (%)	5.57 (5.43)	4.62 (2.97)	4.83 (2.82)	4.62 (2.68)	4.75 (3.09)	4.31 (2.85)
	NHR /a/	0.09 (0.20)	0.07 (0.19)	0.06 (0.18)	0.02 (0.02)	0.02 (0.03)	0.02 (0.03)
	F0 /i/ (Hz)*	158.72 (30.26)	162.54 (29.65)	160.60 (30.73)	173.65 (35.40)	173.93 (31.84)	176.46 (30.52)
	Jitter /i/ (%)*	0.62 (0.42)	0.78 (0.84)	0.75 (0.78)	0.38 (0.18)	0.42 (0.25)	0.37 (0.23)
	Shimmer /i/ (%)	3.06 (1.89)	3.65 (2.82)	3.82 (2.88)	3.06 (2.56)	3.28 (3.24)	2.82 (2.58)
	NHR /i/	0.009 (0.009)	0.01 (0.02)	0.01 (0.01)	0.01 (0.009)	0.01 (0.01)	0.009 (0.01)
	F0-Range Sentences (Hz)	120.78 (26.11)	123.39 (28.92)	118.90 (29.20)	131.41 (32.48)	133.04 (33.36)	134.44 (33.28)
	Amp-Range Sentences (dB)	13.69 (2.85)	13.44 (2.93)	13.40 (3.18)	14.02 (3.13)	14.82 (3.53)	14.37 (3.99)
Self-evaluation	VHI-10*	4.92 (6.55)			0.00 (0.00)		
Perceptual	G*	1.35 (0.68)			0.95 (0.56)		
	R	1.25 (0.87)			0.95 (0.83)		
	B	1.20 (1.03)			0.80 (0.75)		
	A	1.10 (1.04)			0.60 (0.82)		
	S*	1.00 (0.77)			0.59 (0.60)		

* $P < 0.05$.

(shimmer, NHR), or from the reading task (Amplitude-range, F0-range). A summary of these nonsignificant results is presented in the appendix.

Self-evaluation

As shown in Table 1, the mean score obtained from the hyposalivation group on the VHI-10 self-evaluation questionnaire was 4.92, whereas all women in the control group obtained a score of 0 on this questionnaire. An independent-sample t test was performed to examine the group differences, yielding a significant difference between the groups [$t_{(23)} = 3.53$, $P = 0.002$]. It should be noted that the degrees-of-freedom were adjusted in this analysis from 46 to 23, because the variances were significantly different in the two groups [$F_{(1,46)} = 39.02$, $P < 0.001$].

Perceptual scales

Results of the perceptual voice evaluation performed by the group of listeners, using the five GRBAS scales, are presented in Table 1. As shown, the voices of the women in the hyposalivation group were rated consistently higher (ie, more pathological), compared to those of the women in the control group. These group differences were statistically significant for the 'G' and for the 'S' scales [$t_{(46)} = 2.19$, $P = 0.03$; and $t_{(46)} = 2.07$, $P = 0.04$, respectively]. A marginally, though nonsignificant, group difference was found for the 'A' scale

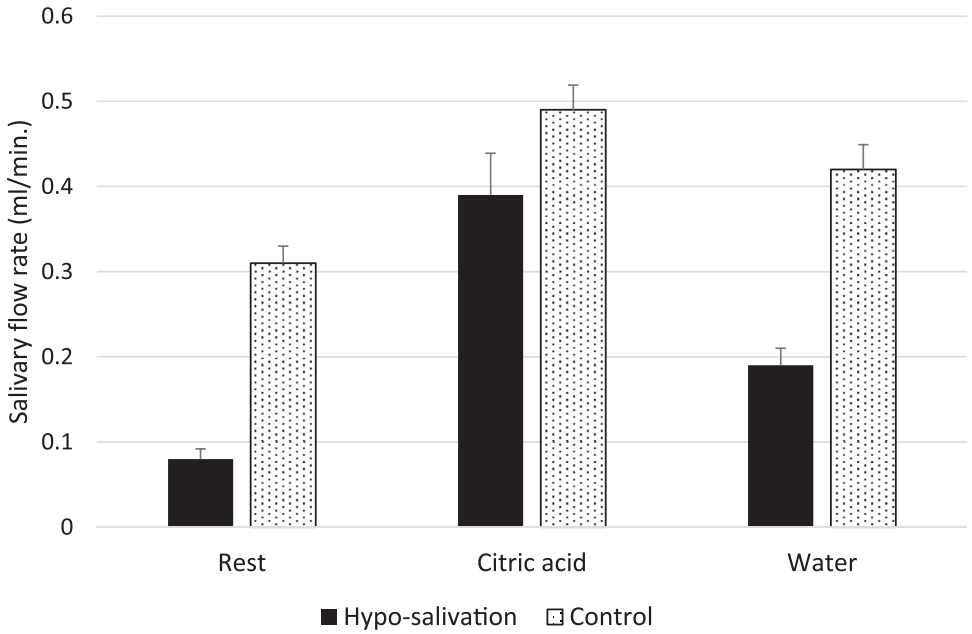

FIGURE 1. Group mean values and standard-error bars for salivary flow rate (mL/min.) obtained from the two groups in the three examined conditions.

[$t_{(46)}$ = 1.86, P = 0.06], whereas the differences observed on the 'R' and 'B' scales failed to reach statistical significance [$t_{(46)}$ = 1.21, P = 0.23; and $t_{(46)}$ = 1.56, P = 0.12, respectively].

DISCUSSION

This study examined the association between hyposalivation and voice, using a set of acoustic, self-evaluation, and perceptual measures. To that end, 24 women diagnosed with subjective and objective hyposalivation were compared to an age-matched group of 24 healthy controls. Results of the sialometry test confirmed that the study group had a significantly lower salivary secretion rates in all test conditions, and that during the rest condition this group was below the clinical threshold of 0.2 mL/min.[17] After gustatory stimulation, the mean salivary flow rate of the test group was below 0.7 mL/min, which still corresponds with the criteria of hyposalivation. It was noted that the control group showed a higher mean salivary flow rate after stimulation, compared to the study group, though not always achieving the expected salivary flow rate of >0.7 mL/min[13] or >0.5 mL/min.[17] This may be explained by the short resting period between the first two phases, which might have exhausted the salivary glands, leading to relatively lower observed values.

Our results demonstrated that refraining from food and drinks for 2 hours facilitated a clear and significant difference between the two groups. Specifically, at the first sialometry test (after 2-hour fasting), the hyposalivation group exhibited a salivary secretion rate that was 3 times smaller than that of the control group. These significant group differences were also evident during the third phase, after water intake. Data also show that while the two latter conditions resulted in an increased salivary secretion rate in both groups, the relative impact of these conditions was greater in the hyposalivation group. In other words, the hyposalivation group benefited more from gustatory stimulation and water intake, compared to the controls.

Group differences

Differences in voice characteristics between the two groups were found in several acoustic measures, in the self-perceptual evaluation questionnaire and in the listeners' perceptual task. In general, the hyposalivation group exhibited a degraded voice quality on most measures, compared to the control group. Following is a brief summary and discussion of these findings.

Results of the acoustic analysis revealed significant group differences in fundamental frequency (F0) and in the frequency-perturbation measure (jitter). While both groups exhibited F0 values that were within the expected range for their gender and age,[28,29] the women in the hyposalivation group showed *lower* values of F0 and *higher* values of jitter compared to the control group. These characteristics are interpreted as demonstrating increased phonatory strain in the hyposalivation group.[33] Moreover, while the values obtained in the control group were always within the expected range for healthy speakers,[33,34] the values obtained in the hyposalivation group were more deviant (albeit within the "normal" range). This may be illustrated, for example, by the jitter values of the vowel /a/. As shown in Table 1, mean jitter obtained from the hyposalivation group for the vowel /a/ during the rest condition was 1.40%, which is higher than the expected clinical threshold.[32] On the other hand, the equivalent value in the

control group was 0.44%. Interestingly, jitter values obtained from the hyposalivation group after local gustatory stimulation and after drinking water were between 0.75% and 0.78%, which are within the expected normal range, yet markedly higher than the values obtained in the control group (0.37% −0.43%).

Comparing these findings to previous studies should be done with caution, due to many methodological considerations. Kim et al,[35] for example, examined a group of female patients with Sjögren's syndrome who had complained about their voices. These women were compared to a group of patients who were treated at the otolaryngology clinic for throat discomfort. In other words, both groups in that study consisted of *non*-healthy patients. In addition, the participants' age in that study ranged between 47 and 62 years (mean age: 55 Years), which is 10 years younger than our participants were. As noted, that study failed to reveal significant group differences in F0 or jitter. Nonetheless, the methodological differences between the two studies and the differences in the inclusion criteria cannot be overlooked. It is, therefore, suggested that these dissimilarities explain the differences between the results of the two studies.

As shown in Table 1, during the isolated vowel task, the hyposalivation group exhibited higher values of amplitude-perturbation (shimmer) and NHR, compared to the control group. Similarly, during the reading task, the hyposalivation group showed a more *limited* dynamic vocal range, evident by the lower values of the F0-range and Amplitude-range measures. Nonetheless, unlike the significant results obtained for F0 and jitter, the differences observed on the shimmer, NHR and vocal range measures failed to reach statistical significance.

The combined results of the acoustic analyses provide empirical evidence for the importance of superficial hydration for phonation, and for the adverse effect of continuous oral dehydration on voice. Nonetheless, it also suggests that not all acoustic measures are equally affected by hydration. Previous studies have shown that those measures that failed to reach statistical significance in our study, have led to significant effects under other conditions. For example, in a study that compared 77 men and women diagnosed with Sjögren's syndrome with a group of 77 healthy controls,[36] significant group differences were reported in shimmer values. Arguably, smaller and less consistent group differences in values of specific measures might require a relatively large sample size, to facilitate statistical significance. Another example for the influence of the study's paradigm can be shown in Roh et al's study,[24] which exposed a group of 20 healthy men to an elicited condition of acute oral dryness. They reported significant effects in measures of voice amplitude and F0-range. Nonetheless, the participants in that study were exposed to an extreme dryness condition, beyond the typical clinical status of people suffering from dry mouth. Hence, it appears that acoustic analysis of voice is sensitive to the effects of dehydration. Yet, evidently, the different measures are not equally sensitive to that effect, thus various experimental conditions yield different results.

The differences between the two groups were also observed in the participants' self-perceptual evaluation of voice. As shown in Table 1, the hyposalivation group exhibited a mean value of 4.92 on the VHI-10 questionnaire. Individual values within this group varied greatly and ranged between 0 and 24. In contrast, all women in the control group responded to this questionnaire with the score of 0. This demonstrates that, in general, the women of the hyposalivation group were more concerned about their voice, and that their voice-related quality-of-life was lower than that of the control group. This conclusion is supported by the results of a few previous studies that demonstrated the effect of dehydration on voice related quality-of-life.[35,37,38] It also highlights the fact that dehydration and hyposalivation influence each speaker differently, and emphasizes the importance of individualized recommendations for hydration in the context of voice therapy.

In addition to the results obtained from the acoustic and self-evaluation measures, the differences between the two groups were also evident in the listeners' perception task. As shown in Table 1, the five professional listeners rated the voices of the participants in the hyposalivation group significantly higher on the Grade and Strain scales, compared to the control group. This finding is compatible with the results obtained from the acoustic analysis. As noted above, the lower F0 values combined with the higher jitter values observed in the hyposalivation group are viewed as a representation of a more strained voice production pattern. Hence, the perceptual judgment of these voices as more strained is in line with the instrumental acoustic analysis.

Two issues should be noted here. First, the R, B, and A scales (ie, Roughness, Breathiness, and Asthenia) did not yield significant group differences. Yet, the group-difference pattern on these scales was similar to the G and S scales (Grade and Strain), which yielded significant results. In other words, all perceptual scales demonstrated reduced voice quality in the hyposalvation group, but only the G and S scales have reached statistical significance in this study. Second, the mean values obtained for the hyposalivation group on the perceptual scales ranged between 1.00 and 1.35. This suggests that although listeners rated these voices as more pathological than the voices of the control group, the hyposalivation group was rated as exhibiting mild-to-moderate voice disturbances, but not as more severe than that.

Condition differences

In contrast with the significant group differences described above, our data did not reveal statistically significant differences among the three study conditions (rest, citric acid, water). As noted, differences between the three conditions in this study could only be examined using the acoustic analyses, because all other measures were tested only once, prior to the study manipulations. Inspection of the data reveals a general improvement in voice characteristics after oral gustatory stimulation and after drinking water, compared to the rest condition. Furthermore, this improvement was more evident in the

hyposalivation group, compared to the control group. Nonetheless, these observed differences failed to reach statistical significance, and should be, therefore, discussed as such.

As noted above, the significant differences between the study group and the controls suggest that a continuous state of superficial dehydration (caused by chronic dry mouth and hyposalivation) may have an adverse effect on the voice mechanism and on voice quality. On the other hand, our data show that changes in *short-term* superficial hydration levels produced a lesser effect on voice. These observations should interpret with caution because the study group in this study included patients with various etiologies for their hyposalivation. It is, therefore, possible that other systemic factors have contributed to the differences observed in voice characteristics. Indeed, future studies with larger sample size and more strict differentiation between patients with different systemic backgrounds are needed to assess this issue. Nonetheless, such studies present a real methodologic challenge, since many patients with hyposalivation present multifactorial etiologies for their condition of dry mouth, as well as a combination of medication intake and underlying systemic conditions.[17]

Finally, as shown in Figure 1, stimulating salivary discharge has indeed increased oral hydration. However, this increase was not sufficient to facilitate an immediate and statistically significant improvement in voice properties. Interestingly though, the favorable effect of gustatory stimulation and drinking water on superficial dehydration was more evident in the hypohydration group than in the controls. Nevertheless, this observation should be considered carefully, as all examined Group X Condition interactions failed to reach statistical significance. Therefore, future research with a larger sample size should revisit this question directly, to shed more light on this topic.

CONCLUSION

Maintaining hydration is important for the vocal mechanism and for voice quality. Women dealing with oral-dryness were shown to exhibit degradation in voice quality, evident in both acoustic, perceptual, and self-evaluation measures. In contrast, within the present study, short-term superficial oral hydration was not associated with a statistically significant improvement in voice. Therefore, it is recommended that voice users and voice professionals be informed on the adverse effects of dehydration on voice, and that maintaining a continuous long-term state of superficial hydration is beneficial to voice quality, especially among people suffering from hyposalivation or oral-dryness.

APPENDIX

A summary of the nonsignificant results obtained from the acoustic measures extracted from the isolated vowels and the reading passage

Stimuli	Measure	Group Differences (Df = 1, 46)	Condition Differences (Df = 2, 46)	Interaction (Df = 2, 46)
Vowel /a/	Shimmer	$F = 0.31$, $P = 0.57$	$F = 0.94$, $P = 0.37$	$F = 0.52$, $P = 0.59$
	NHR	$F = 2.10$, $P = 0.15$	$F = 1.38$, $P = 0.25$	$F = 1.40$, $P = 0.25$
Vowel /i/	Shimmer	$F = 0.20$, $P = 0.65$	$F = 0.94$, $P = 0.39$	$F = 1.23$, $P = 0.29$
	NHR	$F = 0.03$, $P = 0.86$	$F = 1.50$, $P = 0.22$	$F = 0.29$, $P = 0.74$
Reading	F0. range	$F = 1.98$, $P = 0.16$	$F = 0.26$, $P = 0.77$	$F = 0.55$, $P = 0.57$
	Amp. range	$F = 0.76$, $P = 0.38$	$F = 0.18$, $P = 0.82$	$F = 0.36$, $P = 0.69$

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